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PAR 207

FINAL REPORT

Definitive Study of Contact Printers

Phase I

18 November 1965

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FOREWORD

Early in the Phase I investigations, it became evident that some techniques and procedures could be more accurately and economically determined by doing the majority of the work with Moiré patterns on a vacuum frame with confirming tests made on a Niagara printer. Testing on step and repeat printers has therefore been deferred to Phase II.

Following customer approval, Phase II would involve the evaluation and comparison of the performance of contact printers in accordance with the procedures and criteria established during the Phase I effort, the printers involved in this task to be selected by mutual agreement between the customer and the contractor.

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SUMMARY

Evaluation of contact printers involves gross physical factors as well as detailed image structure analysis. Some discussion of the technical problems encountered in pursuit of these objectives is presented as a means of explaining the purposes of the proposed testing. Because of the complex structure of a photographic image, a single type of image quality measurement cannot be completely definitive. Therefore, a number of different test procedures are proposed, with the intention that all be used and the individual results summed to produce an appropriate final conclusion. Although some of the tests are basically objective, it is advisable to temper all test conclusions with considered subjective judgment. If thus applied, the tests should provide a reliable indication of comparative printer performance.

Most of the procedures described are based on theories and techniques which have been extensively studied in recent years within the photographic community. Sharp-edge test objects have been used in other investigations, but the one discussed herein is prepared by a new technique which is capable of producing superior results. Of particular interest is the study and measurement of distortion by the Moiré technique, which shows considerable promise even in its currently unperfected state. Expansion and refinement of the technique could provide a precise foundation for mensuration beyond current capabilities; it is recommended that such exploitation, through study and practical testing, be authorized.

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SUBJECT: Definitive Study of Contact Printers

TASK/PROBLEM

1. Conduct a comprehensive evaluation of existing contact printers (i.e., flat bed, step and repeat, and drum platen (continuous) types). Primary objective is to determine printer and/or techniques that will provide maximum fidelity of duplication.

INTRODUCTION

2. Evaluation of photographic reproduction systems can be separated into two different but interrelated categories: (1) gross physical effects such as predictability, repeatability, and uniformity, and (2) a detailed study of image structure and quality. Each parameter may be affected by several variables so that simple cause-and-effect relationships are not easily apparent: type and specific kind of film used, processing (physical and chemical factors), ambient conditions of temperature, humidity, and perhaps the physical attributes of the test area. Other less-obvious influences may also be encountered. In general, the gross physical effects can be determined in a fairly simple and straightforward manner with little equivocation. Unfortunately, this is not necessarily true of the rather complicated subject of photographic image evaluation, although with proper safeguards meaningful evaluations can be performed.

3. The purpose of the discussion to follow, and the experimental evidence and proposals presented, is not to develop or expound on theoretical considerations for evaluation of photographic reproduction systems. Rather, it is to provide a series of practical and proven procedures readily applicable to the specific task of evaluating existing contact printers. In a very general way, some brief theoretical comments are included to substantiate and clarify some of the experimental procedures proposed. Many detailed technical papers have been published on the theories of photographic imagery

and image evaluation, should further information of this sort be desired. A representative list of these papers is included in the references.

DISCUSSION

4. Basic Requirements of Contact Printer Evaluation Procedures

a. There are two ways in which printers may be evaluated using any given set of tests and procedures. It is often desirable, or at least most convenient, to conduct performance measurements in such a manner that absolute results are obtained. Specific conclusions such as "percent shrinkage" or "lines per millimeter reproduced" are readily comprehended and may be universally applicable. However, the subject at hand is in many respects too complicated to permit the luxury of absolute evaluation. Instead, for many of the printer attributes, comparative analysis is used to arrive at reliable conclusions.

b. Fortunately, it is often relatively easy to standardize on many of the factors which bear on the evaluations to be performed. Following are the more important items to be observed:

(1) Test methods and procedures must be completely and clearly defined, and conducted in a systematic, precise manner.

(2) The same film type and batch number should be used for all tests of a given description and, ideally, all film samples should come from the same roll. If more than one roll is required, it is imperative that all rolls have identical pre-usage histories. It should be noted, as detailed in a later section, that different tests may require the use of different film types.

(3) All film processing, for a given type of test, must be identical as far as chemistry, agitation, time, and temperature are concerned. Similarly, drying must be held constant. These requirements are most readily met by processing all test samples of one type together, and keeping them intact as a unit through all subsequent handling.

(4) Because practically all test procedures of any description involve a human element such as manual manipulation, observation, judgment, etc., it is highly desirable to have the same person perform all tests of a given type. Further, because of the inherent variability of subjective interpretations, more reliability can be placed in tests which have been conducted and evaluated within a short time span rather than those which have allowed days or weeks to intervene between parts of a comparative series.

(5) Ambient conditions of temperature and relative humidity may be critically important for some printer performance evaluations. This applies equally to the preparation of equipment and other materials needed prior to actually performing the test, the testing itself, and evaluation of the finished test materials. More will be said on this in a later section, but it suffices at this point to state that the use of a single carefully controlled test room where all test equipment and material can be conditioned to a pre-selected temperature and relative humidity, can materially improve the reliability of test results.

(6) Despite the foregoing, it should be said that it is entirely possible to perform various printer evaluations as herein described, in a number of different locations. For example, it may be desired to compare the performance characteristics of Printer A in Laboratory No. 1 with Printer B in Laboratory No. 2. However, even with the same printer models, the same film type, and the same processing formulations and machine type, the two laboratories <u>may</u> not yield comparable results due simply to one or more of the factors discussed in (2) through (5) above. The test results may, however, be valid as a measure of over-all <u>system</u> performance.

5. General Physical Evaluation of Contact Printer Performance. Some attributes of a contact printer, while undeniably important in an over-all design or acceptability sense, are not properly within the scope of this report or are of such an obvious nature as to make detailed discussion unnecessary. Included would be such factors as:

a. Total weight
b. Over-all size
c. Minimum and maximum negative size accepted
d. Print production rate
e. Power requirements
f. Noise and/or heat produced during operation
g. Convenience of operation

No further mention of such attributes will be made. Tests covered by this report are related more specifically to the reproduction quality of which a printer is capable.

6. Image Formation

a. Illumination:

(1) Specific test procedures are presented in Appendix 1. Among the first to be considered are those which evaluate directly discernible illumination effects. Particularly in those printers capable of accepting large-size negatives, field illumination uniformity is of utmost importance. Large-bed, step-and-repeat printers may exhibit both longitudinal and transverse non-uniformity, further complicated by a center-to-corner intensity drop-off. Continuous drum-platen printers may show a transverse non-uniformity, which would be manifested as a longitudinal streak of plus or minus print density. Prints from the latter type of printer may also exhibit a transverse density "banding," likened to the slippage or chatter which can occur in a belt-driven pulley system. Tests for these anomalies are described in Appendix 1.

(2) In addition to the uniformity of illumination, of equal importance is the intensity available at the exposing plane. Lamp stability is of importance both from a short range and a long range point of view. On a daily basis, lamp output should be of the same intensity and spectral quality at the start and finish of a test or production run and, of course, throughout all film footage between. Over a longer period of time, a slow and preferably predictable decline in lamp output may be experienced. This may not be troublesome if:

(a) The printer has a convenient and reliable "lamp calibration" feature which facilitates daily adjustment to a standard illumination level.

(b) The uniformity and spectral quality of the lamp remains essentially constant over a long period of time.

(c) The practical useful lamp life is long enough not to impose a supply or down-time handicap.

(d) Replacement of spent lamps is readily accomplished with a minimum of calibration and checkout effort.

Some of this information is provided in lamp manufacturers' bulletins; other factors require some monitoring as described in Appendix 1.

(3) Two additional attributes of illumination may have a profound effect on image quality. Where lamps of different spectral output are being considered, it should be noted that shorter-wavelength illumination such as the ultraviolet emanation of high-pressure mercury vapor lamps inherently produces better resolution than do the longer wavelengths of tungsten lamps. The specularity of the illumination also has a direct effect; a diffuse source may exhibit better uniformity but a specular source will yield higher resolution. Some printers may offer a choice of illumination source, while others will not.

b. Mechanical:

(1) The film transport system of a printer is closely tied to reproduction quality capabilities. The loading and threading cycle must be such that incorrect operation is unlikely, and potential scratching or other physical damaging of the negative or raw print stock is readily preventable. Tracking of the two films through the printer, either with respect to each other or to a "normal" running position, must be positive enough so that no misalignment is apparent. Fundamental to all these factors is, of course, the physical design of the printer: type of film supply and take-up spindles, drive mechanism, type and placement of guide rollers, etc. But of equal importance is the pressure or tension applied to the two strands of film, particularly at the point of actual exposure.

(2) In some printer models, tension applied to the negative roll and the raw-stock roll can readily be adjusted. Incorrect tension can lead to poor film-to-film contact, slippage, stretching, and poor tracking, resulting in various types of image distortion. Because direct tension measurements are difficult to make in an accurate and meaningful manner, an indirect photographic technique has been devised which neatly discloses and measures the dimensional-quality anomalies which might be encountered. This technique is discussed later in the discussion section on Distortion, and makes use of the Moiré pattern. Examples of such patterns are seen in everyday life such as overlapping window screens or picket fences.

7. Films for Printer Use and Evaluation. As implied in some of the preceding discussion, the choice of film has a very significant effect on the quality of photographic reproduction. Since various films have different photographic speeds (exposure factors), they also vary in apparent graininess. Differences in contrast and attainable density also vary over a wide range. But sometimes overlooked is the fact that different film may have considerable effect upon final photographic quality, caused by, for example, the relative transmission of ultraviolet radiation, or antihalation

coatings. The several types of support commonly used today are, in general, similar in their optical properties, while their physical attributes are quite different.

a. Characteristics:

(1) The original cellulose nitrate film support was replaced long ago with safety film, a cellulose triacetate formulation which is in most respects very satisfactory as a carrier for the photographic emulsion. However, the triacetate material tends to dry out and shrink with age, and can also be stretched and somewhat deformed, particularly when relatively fresh. Longitudinal and transverse changes are apt to be significantly different. With the advent of aerial mapping and reconnaissance, there was need for a material which was more stable, or at least more uniform and predictable. A cellulose acetate butyrate formulation, known as topographic support, was developed, in which expansion or shrinkage could still be expected but would be essentially the same in any direction in the film. In recent years a polyester support with the trade name of Estar has been introduced which is a marked improvement over previous types. However, changes in dimension due to tension, heat, humidity, or aging can still take place, so all due precaution should be exercised in handling or storing the raw or processed film. As an indication of the magnitude of the dimensional changes which might be encountered, see Table 1. This table summarizes the stability factors of some representative film types.

(2) The choice of film to be used in any given situation will of necessity be based on several considerations. Spectral sensitivity, photographic speed, resolution capability, exposing system, and processing requirements are among the more obvious factors. An ultra-fine-grained duplicating film may not be usable with a coarse-grained negative without the possibility of reproducing the actual grain pattern, resulting in a blotched condition commonly called "print measles." In addition to the

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Table 1

APPROXIMATE DIMENSIONAL CHANGE CHARACTERISTICS OF KODAK AERIAL FILMS

FILM TYPE	Kodak Plus-X Aerographic Film TYPE 5401		Kodak Plus-X Aerecon Film TYPE 8401		Kodak Plus-X Aerecon Film, (Thin Base) TYPE 8402		Kodak Plus-X Aerial Film (Estar Thin Base) TYPE 4401	Kodak Special Plus-X Aerial Film (Estar Base) TYPE SO-135	Kodak Special Aerial Duplicating Film (Estar Thick Base) TYPE SO-117
Type of Base	Cellulose Acetate Butyrate		Cellulose Triacetate		Cellulose Triacetate		Estar Base	Estar Base	Estar Base
Nominal Base—Thickness (Inches)	.0052		.0052		.00275		.0025	.0040	.0070
DIRECTION OF TEST	Length	Width	Length	Width	Length	Width	*	*	*
Humidity Coefficient of[1] Linear Expansion. % per 1% RH (Unprocessed)	.0070	.0075	.0055	.0070	.0080	.0100	.0035	.0025	.0015
Thermal Coefficient of[2] Linear Expansion, % per Degree F	.0042	.0044	.0025	.0035	.0025	.0035	.0015	.0015	.0015
Processing Dimensional Change, %									
Procedure — RH to Measurement — RH of Film Prior to Measurements: Unprocessed / Processed									
A — 50 — Low / Low	—.06	—.07	—.06	—.08	—.10	—.10	—.02	—.01	—.01
B — 50 — Low / High	—	—	—	—	—	—	—.05	—.03	—.01
C — 10 — High / High	—	—	—	—	—	—	+.03	+.02	+.02
Processing + Accelerated[3] Aging-Shrinkage, % (7 days at 120F —20% RH)	.13	.14	.15	.20	.20	.25	.07	.04	.02
Processing + Long Time[3] Aging-Shrinkage, % (1 year at 78F —60% RH)	.13	.12	.30	.35	.20	.22	.05	.03	.02

*The dimensional properties of Estar base films are nearly the same in all directions of the sheet; the small differences which may exist are not always between the length and width directions.

[1]Measurements made at 70F between 20 and 70% RH for cellulosic films, and between 15 and 50% RH for Estar base films.
[2]Measurements made at 20% RH between 70 and 120F.
[3]Measurements made on tray-processed 35mm x 10-inch specimens.

NOTE: This table is reproduced from the Manual of Physical Properties of Kodak Aerial and Special Sensitized Materials.

previous comments concerning various film supports, there are the facts that, in general, thicker supports are more dimensionally stable, but thinner supports allow a greater footage to be wound on a given camera supply spool. It is apparent that the final film selection must involve some degree of compromise based on over-all system requirements.

b. Handling Precautions:

(1) In conjunction with the foregoing, it has been mentioned that all printer evaluation work should be conducted in an area having closely controlled temperature and humidity. This is particularly true when image distortion or other mensuration work is to be performed. Generally speaking, film still sealed in the original manufacturing container has been conditioned to 50% R.H. (relative humidity) and so need only be brought to the ambient temperature of the testing area. If a film container is not tightly sealed, or the film is apt to be exposed for some time to an R.H. other than 50% ± 2% before being printed, it would be advisable to allow the film to equilibrate to the work-room conditions. Heating of the film during the printing cycle, such as can happen in some step-and-repeat printers, should be guarded against as much as possible. After printing, processing, and drying, the test films must again be reconditioned to the original temperature and relative humidity. Handling the finished film over hot illuminators should be avoided as much as possible.

(2) It should be noted here that the required conditioning time for short, single pieces of raw or processed film may be less than an hour, but for tightly wound rolls, twenty-four hours or more may be required.

(3) The need for extreme cleanliness in all film printing and handling operations cannot be overemphasized, as can be most dramatically illustrated by considering this simple fact: aerial reconnaissance uses high resolution film to record detail at extremely small scale, and

even a single speck of dust or lint can obliterate useful photo-intelligence. Therefore, stringent precautions should be taken to eliminate dirt from film handling areas. Operators may need to wear lint-free overgarments (smock, cap, gloves, and face mask).

8. Image Quality

a. General Discussion:

(1) The determination of image quality is a rather complicated and somewhat controversial subject. In recent years there has been a sizeable accumulation of technical literature on the various elements of the subject, and yet differing opinions persist. However, certain basic concepts have been proven to be compatible with practical experience as well as being technically sound, and have become the foundation of present evaluation techniques.

(2) It should be readily apparent that some concepts of "good" pictorial photography do not necessarily apply to the requirements of reconnaissance photography. For a simple example, soft-focus photographs often are aesthetically pleasing but are of little value for aerial photo interpretation. For the latter purpose, resolution and sharpness are more commonly used as measures of image quality. Because of frequent confusion and misinterpretation in the use of these terms, a few basic points of image theory will be included in the following discussion.

b. Spread Function. When a pinpoint of light strikes the surface of a photographic emulsion, the effective exposure is not confined to a fine point of like dimension but rather is spread out due to diffraction, diffusion, and scattering within the emulsion layer. If the pinpoint of light has been attenuated by an interposed photographic negative, further spreading of the exposed area will occur. When a number of such pinpoints are arranged side-by-side in a chain-like array, the result is a continuous line subject to similar effects of image spread. Measurement of this line spreading (spread function) can give a useful measure of image quality. Several types of photographic test objects are available which can be used for a similar purpose, such as short-bar resolution targets intended for visual evaluation or long-bar resolution targets designed to be machine-read. These are discussed in more detail in a later section.

c. Machine-Read Resolution. Normally, a test-target used to evaluate fine-line reproductions consists of groups of at least three identical bars spaced the same distance apart as the width of each bar. Consecutive groups of bars are of a progressively finer scale so that a wide range of "line frequencies", or lines per millimeter, is represented; typically, a test target may include bar groups representing from ten or less up to five hundred or more lines per millimeter. In the original target, all bars of all sizes have essentially the same high density, and the spaces between have the same minimum density; in a reproduction of the original, at higher and higher line frequencies, the bars and spaces tend to blend into each other more and more. A microdensitometer trace across an entire array produces a repetitive high-to-low pattern representing the differences in density. When the high points and low points become indistinguishable, the maximum resolution has been reached.

d. Sine-Wave Response:

(1) The procedure for determining sine-wave response involves a microdensitometer trace of the original test-target and the reproduction of the same target, and comparing the amplitudes of the corresponding sine-waves at each line frequency. A plot of this function; i.e., percentage amplitude reproduced versus line frequency (modulation transfer function), can divulge several pertinent bits of information concerning the quality of the reproduction. Figure 1 shows two illustrative sine-wave response curves from two different types of contact-printing operation.

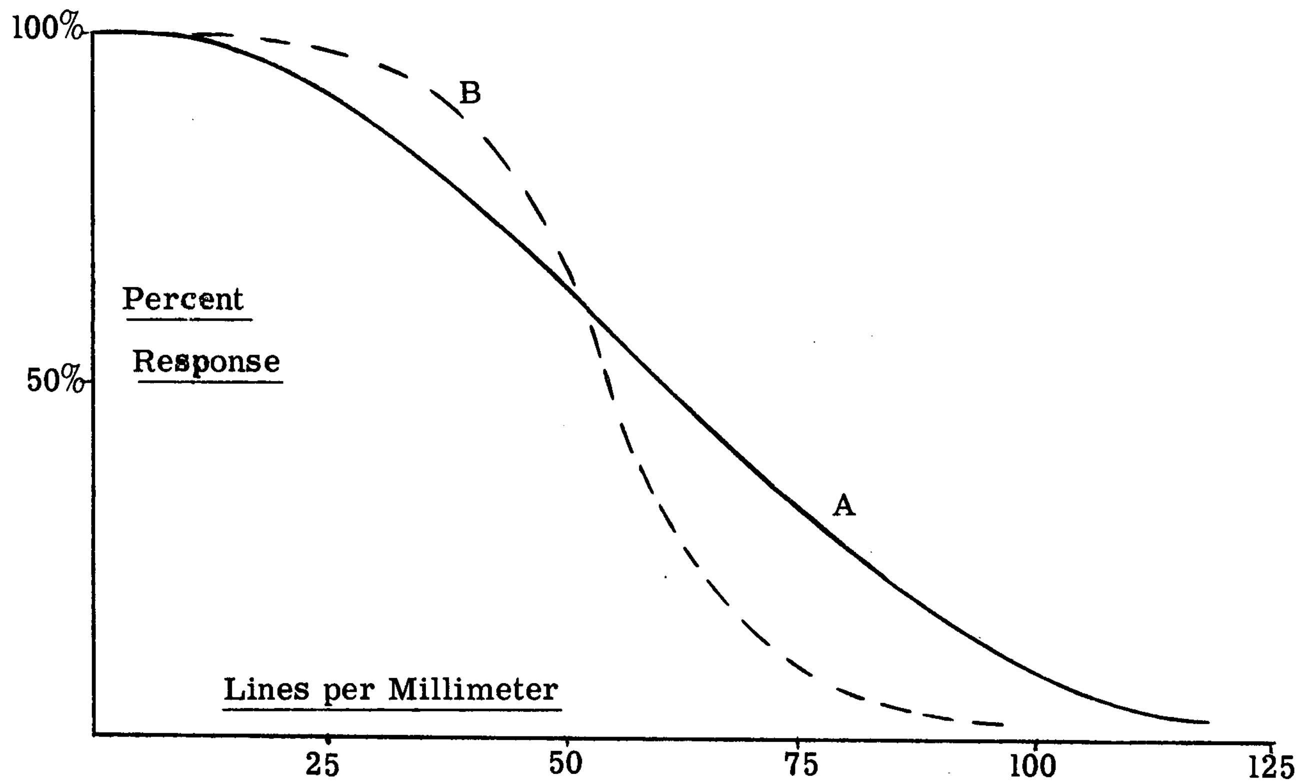

Figure 1. Contrast Transfer Comparison

(2) In Figure 1, we note that both curves A and B show the same high transfer function at a line frequency near zero, indicating little low frequency image degradation. At a frequency of about ten lines per millimeter, which is about the limit of resolution of the unaided human eye, and up to approximately fifty lines per millimeter, curve A has a lower transfer function than does curve B. This indicates that A does not reproduce these middle frequencies as sharply as does B. However, B has reached zero transfer at a maximum resolution of approximately 100 lines per millimeter while A has continued to about 125 lines per millimeter. The reproduction system represented by curve A is therefore superior for retaining fine detail, but the coarser images will be less sharp than those from B. Which is the "better" of the two depends upon the intended use of the system.

(3) The complexity of the modulation transfer approach makes its application to printer evaluation somewhat difficult. However, for a comparative evaluation, test VII of Appendix 1 offers a simplified method which measures the contrast transfer response in terms of density ratios.

e. Visual Resolution:

(1) The sine wave response procedure described above is one way to determine the resolution capability of a reproduction system. Other tests, using test objects which have been designed for machine-reading, give results directly in resolution values; the procedure for using them is given in Appendix 1 (the Appendix of Test Procedures) as Test IX. The visual method, however, is widely used for evaluating resolution because of its convenience and simplicity. One of the more commonly-used test objects for this purpose, the U.S. Air Force Resolution Target (1951), is illustrated in Appendix 2, Figure 2. The groups of three bars vary in line frequency by the factor of the sixth root of two. A newer and somewhat better target, the U.S. Air Force Resolution Target (1962) varies by the twelfth root of two; this is

illustrated in Appendix 2 as Figure 3. The latter form is easier to use and is more reliable because the apparent change in reproduction quality between successive groups of bars is smaller. The procedure for using either test object is outlined in Appendix 1, Test VIII.

(2) It might be pertinent at this point to comment on some of the shortcomings of resolution as a measure of image quality. From the preceding discussion, it can be seen that resolution simply indicates the threshold of detail rendition without regard to the quality of those frequencies less than the maximum. From an operational point of view, visual resolution is troublesome because it is subjective, and is thus dependent upon the acuity of the observer, viewing conditions, etc.

(3) Despite the above shortcomings, resolution is still a popular and worthwhile measure of image quality because:

(a) The reproduction of fine detail is one of the important features of reconnaissance photography.

(b) Results can be readily expressed in comprehensible terms.

(c) Measurement is relatively easy.

f. Sharp Edge Reproduction:

(1) Evaluation of repetitive patterns of fine lines can yield two different measures of image quality; so, too, can evaluation of an edge. The theory behind the practical application of this latter technique is similar to that which has been previously discussed for machine-read resolution and so warrants but brief discussion here.

(2) If a test object is produced such that a very dark area is separated from the surrounding very light area by a straight line of essentially knife-edge sharpness, the resulting target can be used to evaluate the reproduction of sharp edges by a photographic system. However, there are some difficulties with the use of sharp edge targets. Immediately at the knife edge, illumination which reaches the film through the light portion of the test target does not stop precisely at the edge but tends to diffuse beyond the edge. Not only does this produce some exposure within the "unexposed" area of the film, but the exposing light is obtained at the expense of the "exposed" area adjacent to the edge. The quality of the edge is therefore degraded.

(3) A photographic reproduction of a sharp edge target is evaluated by means of a microdensitometer trace across and perpendicular to the edge. The transformation from low density to high density is not accomplished abruptly, but is a relatively gradual change due to the optical phenomena described above. A curve is produced by this trace which must then be evaluated. A widely accepted method of evaluation involves the rather complex mathematical procedure of determining the "average squared gradient of the image-edge profile" commonly called the "acutance." Details of this procedure are given in Appendix 1, Test X.

(4) Aside from the fact that acutance calculation is rather tedious, careful selection of upper and lower cut-off points is required for the gradient measurements. Also, because these average values encompass the entire curve, acutance does not directly reflect the effect of unusually high or low "bumps" or "dips" occurring in the edge trace.

(5) Rather simple and direct graphical interpretations of edge-trace curves have been found convenient and meaningful. Three procedures are listed in Appendix 1, as Test XA, XB, and XC. If edge-trace curves of distinctly different character are evaluated by the three, close

agreement among the calculated ratings may not be found. In practice, it is necessary to temper the purely mathematical evaluation with judgment, caused in part by the following shortcomings of each procedure.

(a) Maximum Gradient Procedure (Test XA). It is possible for two edge-trace curves to have the same maximum gradient and yet have significantly different shapes in the high-density and low-density portions.

(b) Average Gradient Procedure (Test XB). In addition to the problem noted in (a) above, there is the added uncertainty of the "true" ends of the edge-trace curve.

(c) Edge Width Procedure (Test XC). This suffers both of the uncertainties noted above.

9. Comparative Versus Absolute Analysis. The foregoing is not intended to discredit the use of edge traces for image quality evaluation, but rather to emphasize that some subjective judgment must be applied to any objective testing. It is apparent that comparative testing of two or more printers is likely to be much more meaningful than any purely absolute rating.

10. Distortion

a. Definition. For this report, distortion refers to the dimensional difference between an image recorded on a specific section of film and a reproduction of that image recorded on a second section. In general, these sections are contained within the different rolls of film used for duplicating and handling purposes. All duplication considered is the result of contact printing.

b. Study Goals. It was the intent of the distortion studies in this project to develop a means of measuring distortions resulting from web tensions, the bending of film over a drum platen, and other printer-induced effects which are not the result of direct slippage between the negative and the raw stock. Based upon theoretical calculations of the distortions which might occur in contact printing, it was estimated that a suitable device for experimental efforts should be capable of measuring 0.01% distortion.

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c. Background-Moiré Patterns:

(1) From the literature review conducted, the most promising system found which could satisfy the 0.01% sensitivity requirement was a system using the Moiré pattern technique. This technique is currently used in the photogrammetric industry to study film distortion. It seemed ideal since it offered the possibility of measuring distortion in two perpendicular directions simultaneously and detecting 0.01% distortion in localized areas as small as 3" x 3".

(2) A knowledge of Moiré principles and their current photographic applications was developed from the review of several published papers (see References). Using this background, a set of half-tone glass plates was procured and experimental effort was initiated to gain experience with the Moiré technique.

d. Fundamental Relationships:

(1) The mechanism used to produce a Moiré pattern can best be explained by use of simple illustrations. Figure 2 shows a bar pattern. If two such patterns of different frequency spacings are superposed, Figure 3, a new pattern will be formed. This pattern results from a dense bar of one pattern covering a clear space of the second pattern. This condition will exist at a spacing which satisfies the following equation:

$$\left| f_1 - f_2 \right| = \frac{1}{x} \qquad (1)$$

where:

f_1 = the frequency of component pattern 1

f_2 = the frequency of component pattern 2

x = the distance between cancellations

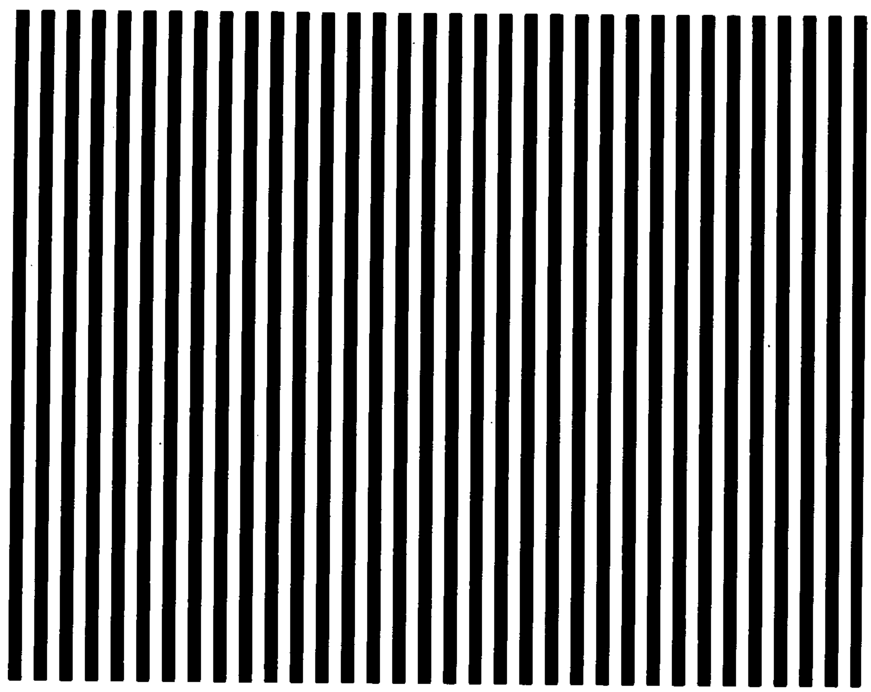

Figure 2. Line Grid "A"
(Evenly spaced dark bars on a light background)

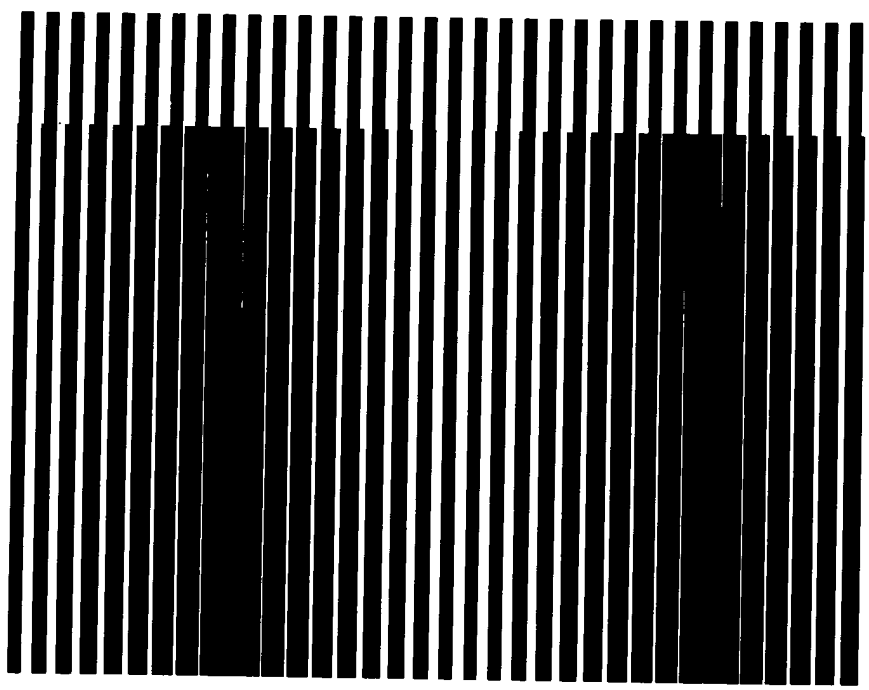

Figure 3. Grid "B" Overlaying Grid "A" Showing Moiré Pattern
("B" is also a grid of evenly spaced dark bars on a light background, but the bar spacings or frequency is slightly different from grid "A")

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(2) It can be seen from equation (1) that knowing the frequency for one component pattern (f_1) and measuring the spacing between cancellations (x), the frequency (f_2) of a second superposed component pattern could be calculated. However, because equation (1) relies upon the absolute value of ($f_1 - f_2$), it cannot be discerned whether f_2 is smaller or larger than f_1. Fortunately, a simple test using the component patterns will determine the algebraic sign of ($f_1 - f_2$). When sliding one pattern relative to the second pattern in a direction perpendicular to the cancellations, the cancellations will move in the direction of the higher frequency component pattern.

(3) For purposes of measuring distortion, which can be expressed as the ratio of a dimensional change to the distance over which the change occurs, equation (1) can be more appropriately expressed in terms of the spacing distances of component patterns. This is accomplished by substituting for the values f_1 and f_2, the values $\frac{1}{d_1}$ and $\frac{1}{d_2}$, respectively, hence:

$$\left| \frac{1}{d_1} - \frac{1}{d_2} \right| = \left| \frac{d_2 - d_1}{d_1 \; d_2} \right| = \frac{1}{x} \qquad (2)$$

where

d_1 = spacing distance of component pattern 1

d_2 = spacing distance of component pattern 2

From this, the following distortion equation is evident where d_1 is considered the standard:

$$D \equiv \frac{d_1 - d_2}{d_1} = \frac{d_1 \; d_2}{d_1 \; x} = \frac{d_2}{x} \approx \frac{d_1}{x} \qquad (3)$$

where D is the distortion expressed as a ratio.

(4) Equation (3) incorporates an approximation, $d_1 \approx d_2$, which is sufficiently correct for small distortions. This can be verified by an example. Assume a distortion of 0.001 shrinkage (i.e., 0.1%) is to be measured using a grid of 200 lines per inch (i.e., $d_1 = 0.005$ inch). The cancellations would appear at a spacing of 5.00 inches. Using the approximation in equation (3),

$$D_1 = \frac{d_1}{x} = \frac{0.005}{5.00} = 0.001 = 0.1\%$$

With the assumed distortion of 0.001, the distorted spacing is $d_2 = (1.000 - 0.001)\, d_1$, and using the exact part of equation (3):

$$D_2 = \frac{d_2}{x} = (1.000-0.001)\,\frac{d_1}{x} = \frac{d_1}{x} - (0.001)\,\frac{d_1}{x} = D_1 - (0.001)\,D_1$$

(5) The error, E, between the two equations is clearly:

$$E = \frac{D_1 - D_2}{D_2} = \frac{D_1 - \left[D_1 - 0.001\, D_1 \right]}{D_1 - 0.001\, D_1} = 0.0011 = 0.11\% \qquad (4)$$

It can be seen from (4) that the error is very small.

e. <u>Halftone Grids</u>:

(1) Although the explanation for Moiré patterns has been presented for one-dimensional distortion using line-type patterns, the principle can be applied in two perpendicular directions simultaneously by fabricating grids from mutually perpendicular line patterns. Thus, the grid has a checkerboard appearance and is commonly referred to as a halftone grid, as half the area transmits light and half does not. Superposition of two slightly different grids will produce a checkerboard array of cancellations as in Figure 4.

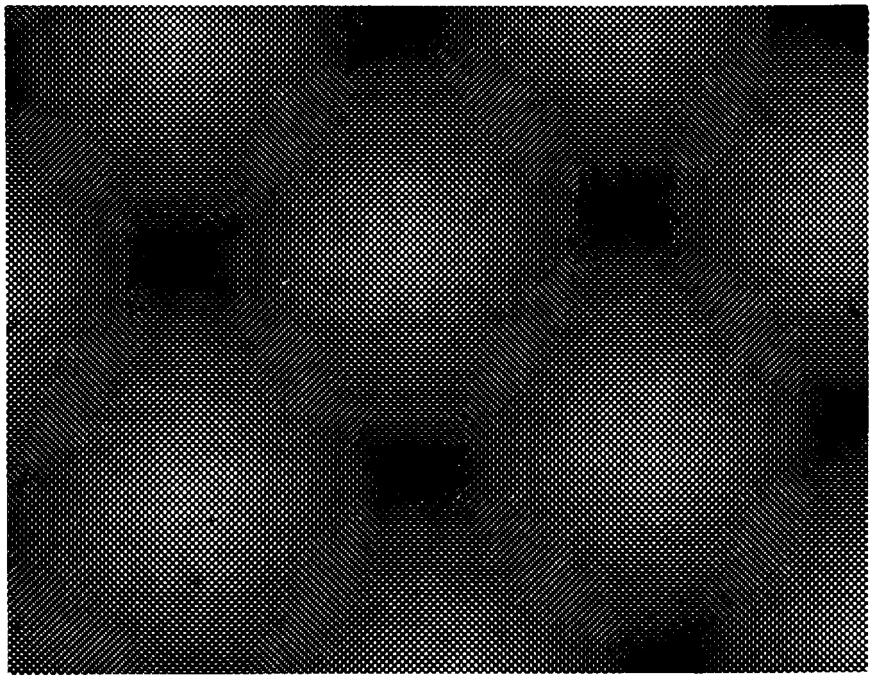

Figure 4. Overlay of Coarse Halftone Grids Showing Moiré Pattern
(Dark areas are cancellations characteristic for halftone grids, just as those of Figure 3 are characteristic for line grids).

(2) The grids used for this project had a spacing of 300 lines per inch. It should be noted, however, that this frequency refers to lines running at 45° to the edge of the grid, as in Figure 5. Hence, the spacing of the squares, d_1, as used in equation (3) becomes $2\left(\frac{1}{300}\cos 45°\right)$ = 0.00472 inch.

(3) Using a given halftone grid as a master, a contact print can be fabricated and registered with the master. Upon registration, dimensional differences as a result of duplication will create a cancellation pattern. Equation (3) can then be implemented to calculate the distortion occurring between adjacent cancellations. It is important in the registration process that the grids be of opposite polarity. Although theoretical consideration of Moiré patterns does not impose a polarity restriction, practical application with like polarities requires nearly perfect halftone grids. Currently available grids do not satisfy this criterion.

f. Methods for Finer Measurement:

(1) It is evident from equation (3) that d_1 must be a stable dimension if it is to be used as a standard for long periods. For this reason, the master grid is fabricated using a photographic glass plate. The size of the grid for this project was 11" x 11" on a 12" x 12" x 1/4" plate.

(2) An inherent lower limit of distortion which can be detected with the conventional system using 300 lines per inch grids is:

$$D = \frac{d_1}{x} = \frac{0.00472}{11} = 0.00043 = 0.043\%$$

where

d_1 = the spacing distance of a 300-line-per-inch grid

x = the maximum cancellation spacing; i.e., the length of the grid.

This limitation therefore makes the conventional system unusable for detecting 0.01% distortion. However, a modified system has been developed with increased sensitivity.

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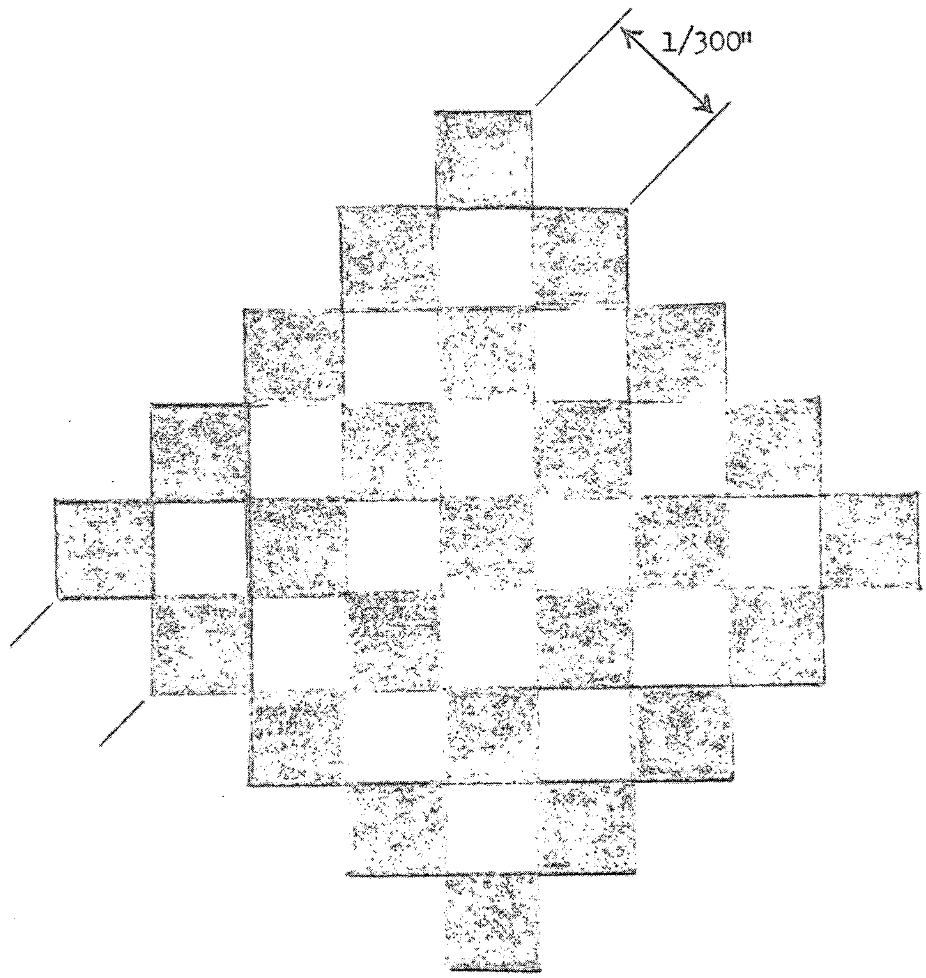

Figure 5. Illustration of Fine Halftone Grid Pattern (300 Lines per Inch)

(3) The principle of the modified system is to use two glass master plates with a known uniform distortion existing between them. In this way, prints of one plate will create a Moiré pattern when registered with the second plate, even if the duplication is distortionless. This would represent the known distortion purposely built-in. If the duplication system introduces distortion, as is usually the case, it will be detected as the measured distortion minus the built-in distortion. The measuring system now relies upon the calculation of differences to assess distortion. Such a technique can provide sensitivity which is limited only by the experimental error in measuring the values of the master grid spacing (d_1), the cancellation spacing (x), the built-in distortion (D'), and the ability to maintain a stable D'.

(4) To implement the modified system, each master plate must have a glass plate copy. This is necessary to determine the built-in distortion since only grids of opposite polarity are registered to form the desired Moiré pattern. It is assumed that the fabrication of glass plate copies is distortionless; hence, the distortion measured between master plate 1 (Figure 6) and copy plate 2 represents the distortion between master plate 1 and master plate 2.

(5) The use of very fine grids such as the 300-line-per-inch halftones used for this project, requires intimate contact between the grids for registration to produce a Moiré pattern. This can be obtained by placing the grids in a vacuum frame located over an illuminator. Figure 7 is a photograph of the vacuum frame used for this project. The top and bottom frames are covered with plastic sheeting which collapses upon the grid plates when a vacuum is created. The top and bottom frames are hinged for convenience.

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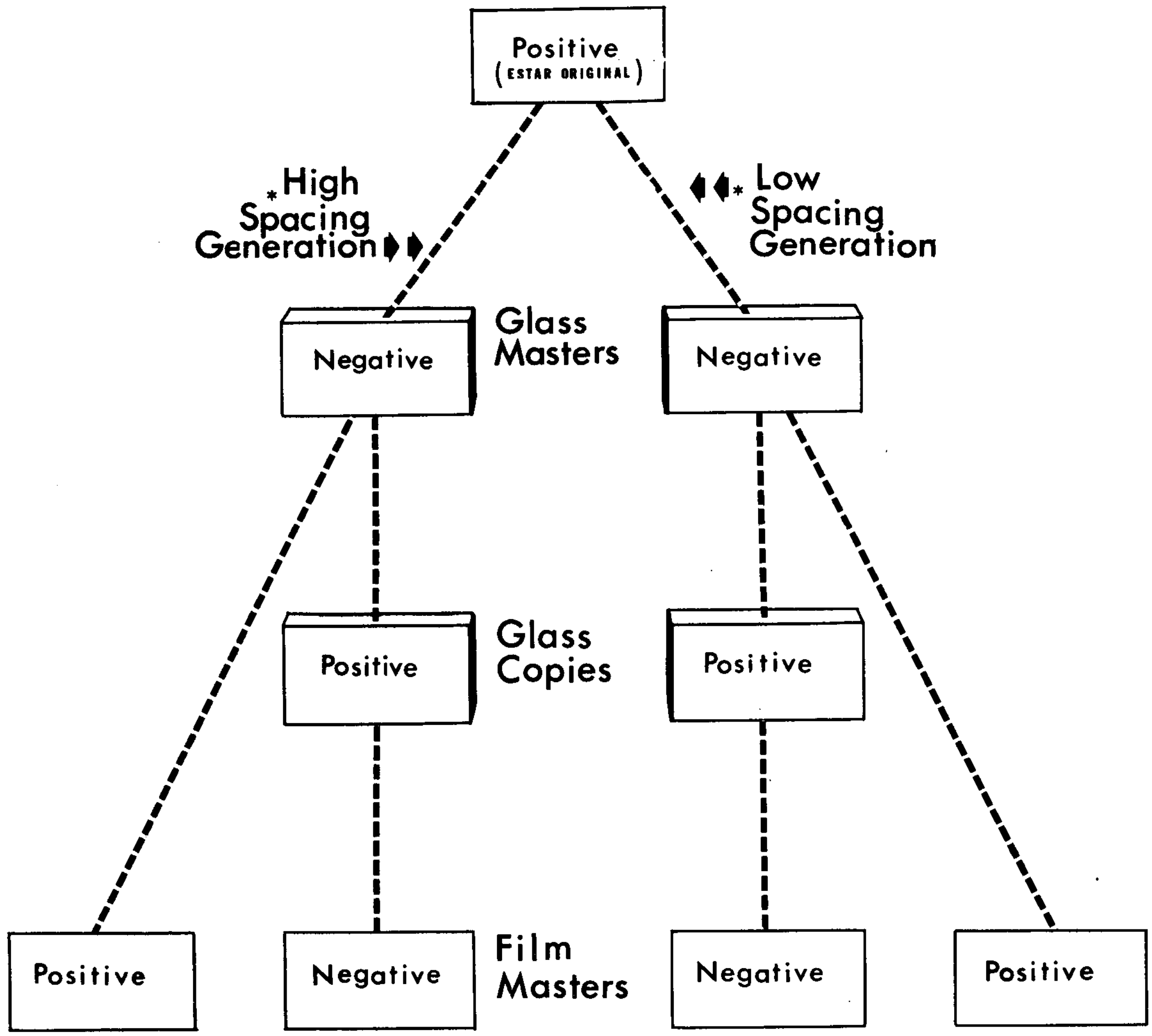

* TEMPERATURE – HUMIDITY CONDITIONS HAVE A DIRECT EFFECT ON LINE SPACINGS. THE HIGH SPACING (Low Frequency) GLASS MASTER WAS PRODUCED WITH HIGHER TEMPERATURE & HUMIDITY THAN THE LOW SPACING GLASS MASTER

Figure 6. Basic Generation Scheme for Halftone Masters and Duplicates

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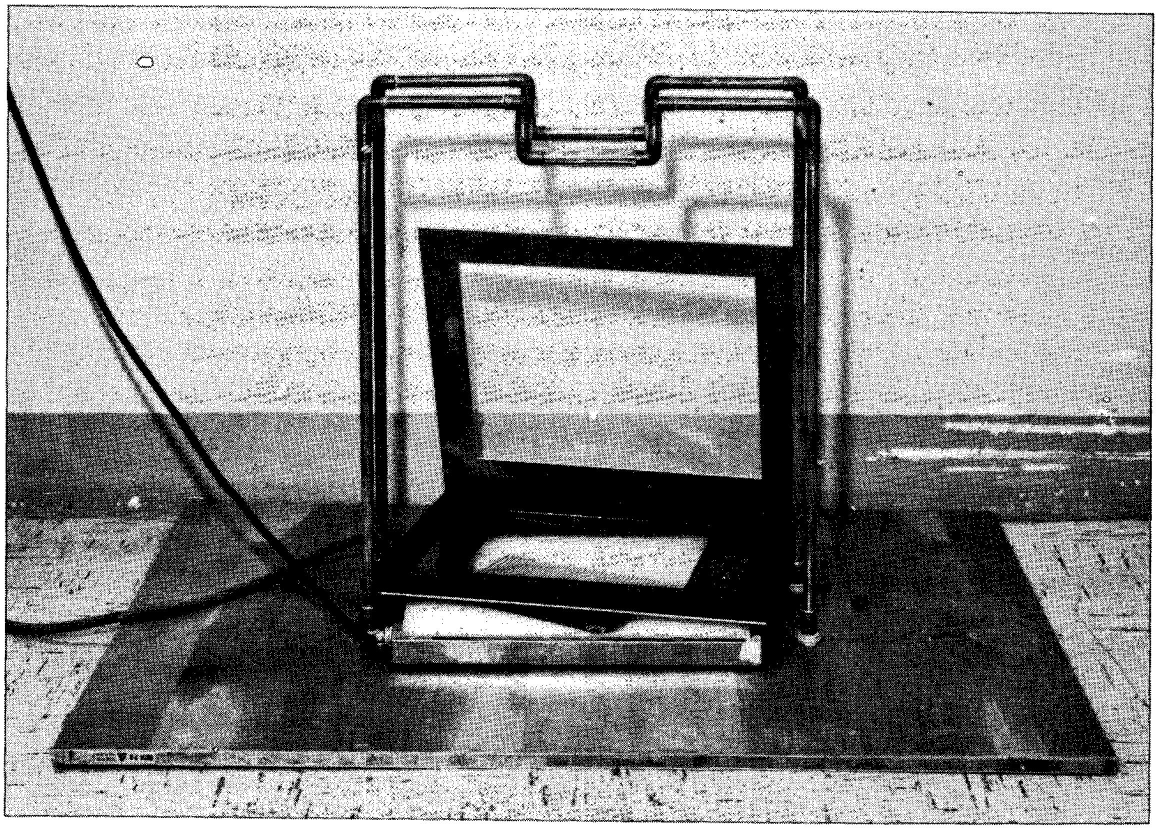


Figure 7. Vacuum Frame and Illuminator

(Frame is shown opened along hinged back with thick line for vacuum connection —— Illuminator shown with frame pushed to rear for scanning transparencies; thin line is power supply)

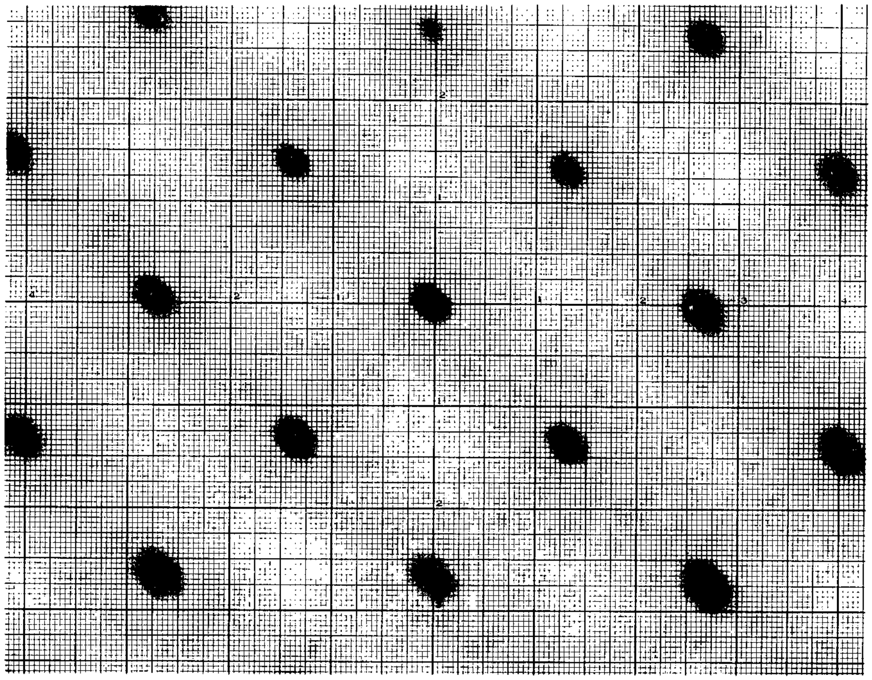
(6) The Moiré pattern spacing resulting from the registration of two halftone grids is highly dependent upon the relative rotation between the grids. The principles presented in this report are based upon the grid lines of two halftones being parallel. This condition can be identified easily since the cancellations are always spaced farther apart when the relative rotation is 0°. Considering the situation of a uniform directional distortion, the cancellations will form a diamond pattern when zero rotation exists and the diagonals of the diamond will be parallel to the edges of the plates. Furthermore, the lengths of the diagonals are inversely proportional to the distortion associated with the diagonal direction. Figure 8 illustrates the effect of relative rotation between the grids.

g. Registration and Printing:

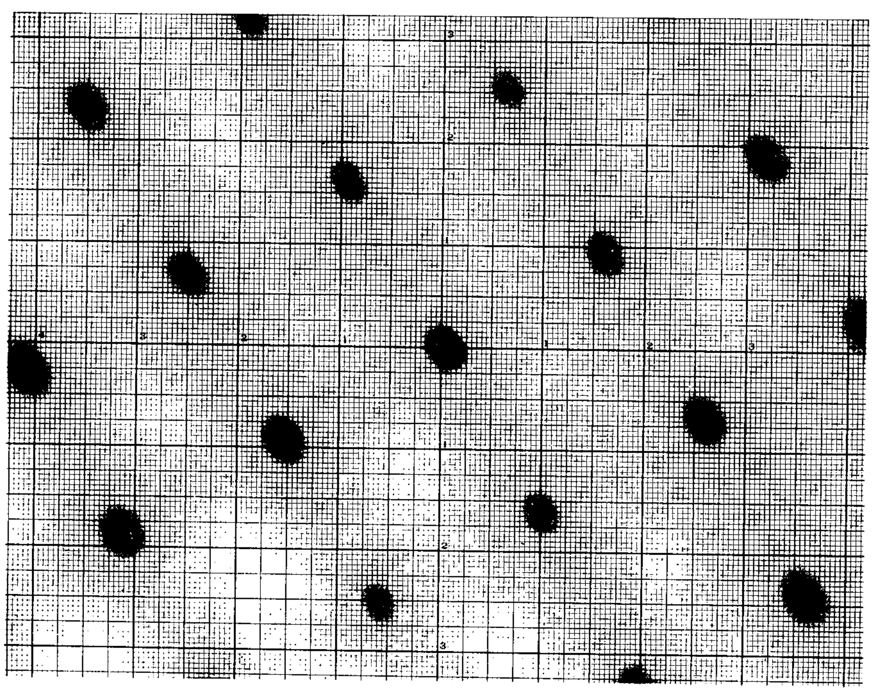
(1) For purposes of clarity and ease of presenting results, it becomes important to define a set of Cartesian coordinates to specify the distortion field. The notation adopted for this project assumes the "x" axis parallel to the length of a roll of film, the "y" axis transverse, and the axis center at the center of both grids. At the point $P_{(o,o)}$, or x = 0 and y = 0, the respective grid centers of each component grid are superposed, and because the grids are of opposite polarity, a cancellation occurs.

(2) The cancellation occurring when the grid centers are perfectly superposed can be distinguished from all other cancellations in the field. It displays a much finer texture and denser center. This cancellation is, in fact, the only cancellation in which the dense squares of one grid truly cover the transmitting squares of the second grid. All other cancellations only approximate this.

(3) A convenient method of aligning the centers of halftone grids is to look for flaws or scratches transferred to the grids from the parent glass plates. Such defects are of opposite polarity and can be aligned quickly by eye. Once the correct registration is obtained, the vacuum frame can be closed and a vacuum applied.



A. In register - no rotation



B. Out-of-register - less than one degree of rotation

Figure 8. Moiré Patterns With and Without Rotation of Grids

(4) The application of the Moiré technique to contact printers involved the fabrication of an intermediate master grid on a flexible support. As Estar base film was the most stable material available, it was used to make the master. The intermediate halftone pattern was exposed onto 5-mil material from a master glass plate using a vacuum frame to maintain intimate contact. Because the intermediate master is not a distortionless replica of the parent plate, it is necessary to measure the distortion and subtract it from future measurements when the intermediate is duplicated in a contact printer. The illustration in Figure 9 will clarify the family of halftone grids required for investigating contact printers.

(5) When registering a film copy of a halftone grid with a glass master grid, an additional clear glass plate is required. After placing the glass master in the vacuum frame emulsion up, the film duplicate is superposed with emulsion down followed by a clear glass plate. It is imperative that the clear plate be optically flat to yield good contact within the sandwich. After registering the grids, the frame is closed and a vacuum applied.

h. Measurement and Calculation:

(1) A Moiré pattern found in a vacuum frame as described above readily supplies qualitative information. Since a uniform distortion causes uniformly spaced cancellations, an observer can detect relative distortion differences by looking for closely spaced cancellations and bending of cancellation rows as in Figure 10. The Moiré pattern, however, from contact printer duplication is a composite resultant of duplication distortion and the intermediate film master distortion. Hence, a quantitative analysis is preferable in which intermediate master grid distortion can be subtracted. Furthermore, the uniform built-in distortion, D', (as described earlier to increase sensitivity) can be subtracted to yield an absolute value for the net system distortion (i.e., printer + processor, etc.).

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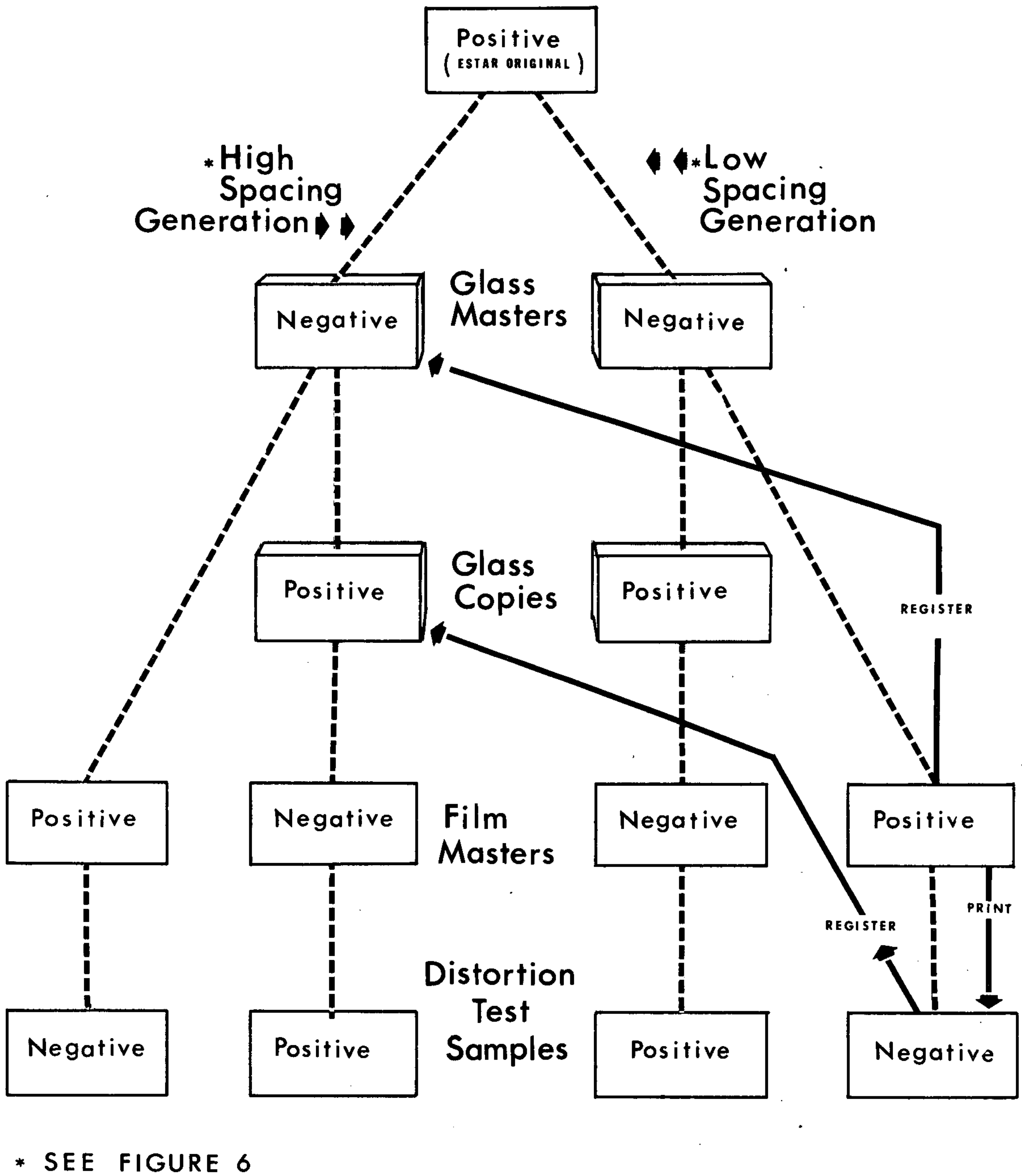

Figure 9. Full Generation Scheme for Halftone Grids

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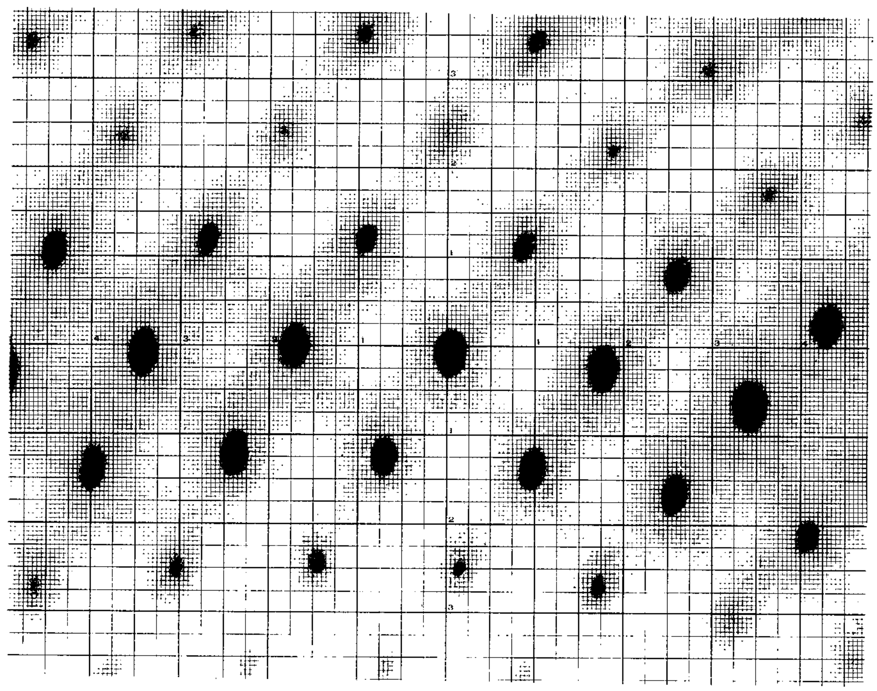


Figure 10. Moiré Pattern Indicating Nonuniform Distortion

(2) The calculation of quantitative information is based upon knowing the distance between cancellations. This data is used in equation (3). A convenient method of obtaining the data is to overlay the Moiré pattern with a Cartesian coordinate grid. A grid of 20 divisions per inch works well. By noting the coordinates of the cancellations, subsequent calculation of distances between cancellations then can be made easily. Making use of digital computer programs, the coordinates of the cancellations can be fed into the computer to yield the end values of distortion directly.

(3) For purposes of this project, a computer program was developed to calculate the X and Y components of distortion between adjacent cancellations located on the diagonals of the typical pattern shown in Figure 11. This program also computed the over-all average X and Y distortion components; i.e., in the length and width directions.

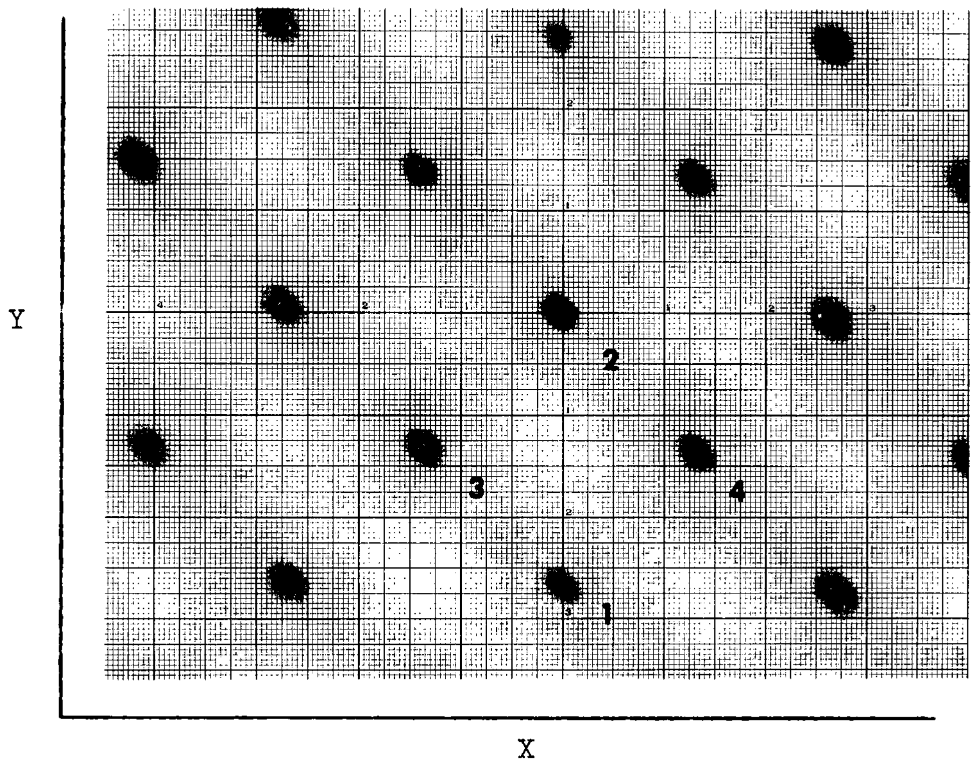
i. Reflection Print Technique:

(1) Although the direct recording of cancellation coordinates is an obvious method of collecting the necessary data, an alternative method was found to be equally accurate, and was superior in many respects. The alternative method is to make a reflection print (3 1/2" x 4 1/4" Polaroid prints were found satisfactory) of the Moiré pattern with a grid overlay. From such a print, the coordinates of cancellations can be determined. This system offers the following advantages:

(a) A permanent record is formed.

(b) The pattern is formed quickly with less possibility of changes occurring due to ambient conditions.

(c) The use of a high contrast print makes the cancellation centers easier to locate.



$$D_y = \frac{d}{y_2 - y_1}$$

$$D_x = \frac{d}{x_4 - x_3}$$

Figure 11. Scheme for Calculation of Local Distortion Using Four Cancellation Points

(Heavy Graph Lines are One Inch Apart)

(d) The effect of parallax encountered with the direct-reading technique is minimized.

A simple bracket, as shown in Figure 12, is useful to hold the camera above the vacuum frame.

(2) To investigate the repeatability of the reflection print technique, a Moiré pattern was photographed and the resulting print was analyzed four times by the same technician. The print contained 25 cancellations from which 18 distortion values could be calculated for the X and Y directions for each of the four readings. The following results were obtained:

Reading No.	Average X Component (% Distortion)	Average Y Component (% Distortion)
1	-0.1888	-0.1909
2	-0.1888	-0.1906
3	-0.1887	-0.1910
4	-0.1894	-0.1906

Additional analysis indicated that each of the 18 distortion values resulting for each reading of the print varied within an average range of zero to 0.002% distortion from four repeated readings. This figure was true in both the X and Y direction. The halftone grids used in this exercise were the low-frequency intermediate film master registered with the high-frequency glass copy master (see Figure 9).

j. Repeatability:

(1) The Moiré technique was also examined to determine the variation from repeated measurement of a given distortion. Using the same halftone grids that were used for examining the repeated readings of a Polaroid print, nine successive registrations were made and photographed. Each photograph was analyzed and the positions of cancellations were recorded. This information was fed into the computer which calculated the following distortions:

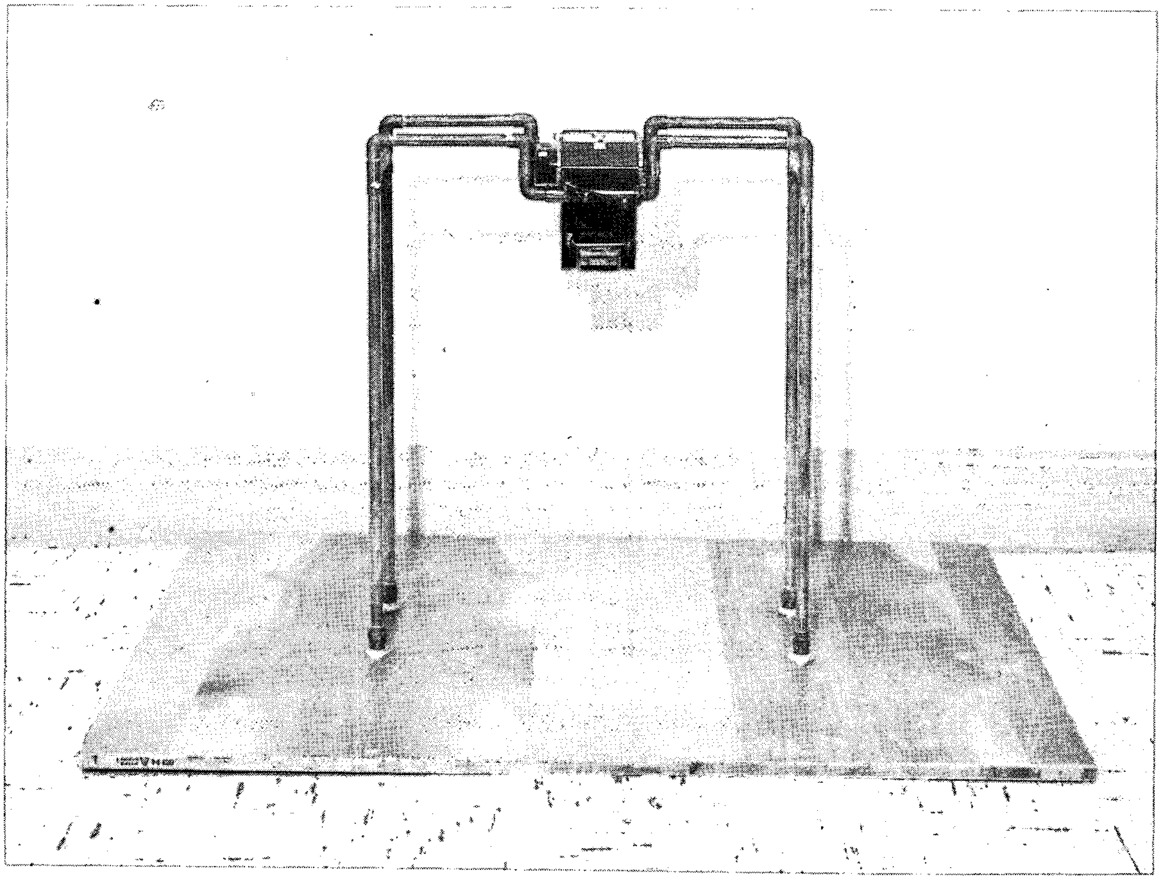


Figure 12. Camera Bracket for Reflection Prints
(Camera shown in bracket was used for making Polaroid prints — camera angle should be as nearly vertical as possible)

Registration No.	Average X Component (% Distortion)	Average Y Component (% Distortion)
1	-0.1894	-0.1928
2	-0.1905	-0.1930
3	-0.1898	-0.1924
4	-0.1896	-0.1924
5	-0.1887	-0.1914
6	-0.1916	-0.1943
7	-0.1918	-0.1949
8	-0.1911	-0.1938
9	-0.1909	-0.1932
Average of 9 Registrations:	-0.190	-0.193
Range:	0.003	0.003
Standard Deviation:	±0.00084525	±0.0010568

(2) The preceding investigations indicate the Moiré technique to be satisfactory as a tool for repeated measuring of distortions as low as 0.01%. The variation of values occurred consistently at one order of magnitude below the desired sensitivity limit. As for the accuracy of the system, however, there is a lack of evidence.

(3) Presently, the Moiré technique is in a class by itself. There appears to be no standard with which to compare it, and no simple, reliable test to evaluate it. The Moiré principle is simple and sound, however, and one may expect good results with this technique.

k. Niagara Printer Test:

(1) The Moiré technique was implemented on a trial study of Niagara printer distortions. Exposures were made of the low frequency intermediate film master onto 9.5-inch duplicating material, Type SO-117*

* Type SO-117 is a 7-mil Estar base material and is considered the most stable of available flexible base films.

(see again Figure 9). A total of 13 samples were made. The raw stock tension was adjusted to a low level where only very small tension variations occur throughout the printing of a roll. The negative tension was set at two levels: a high level for 8 samples, and a low level for 5 samples. The negative tension difference was calculated to be 6.5 lbs. From the 8 high tension samples, 3 received standard machine processing, and 5 received tray processing with room drying. From the 5 low tension samples, 2 received standard machine processing and 3 were tray processed. The distortions measured are listed in Table 2.

(2) The distortion values in Table 2 represent a composite of printer effects, process effects, and ambient effects; however, the difference between high and low tension can be related directly to the 6.5 lbs. tension change on the printer. This assumes, of course, that other effects remain constant. All of the values are negative. This indicates shrinkage, and therefore it is clear that high web tension in the negative transport will compensate partially for this to reduce the total distortion.

(3) It is interesting to note that analysis of the film using conventional stress-strain theory for the situation of changing the web tension by 6.5 lbs. yields a calculated strain of 0.024%.

1. Capability and Limitation Factors:

(1) Although the repeatability exercises with Moiré techniques indicated excellent results, experimental test conditions can have a significant influence. The best available information describing humidity and thermal coefficients for common Estar and acetate base films is:

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Table 2

DUPLICATING SYSTEM DISTORTIONS*

Sample No.	Tension Level	Process	% Distortion "X" Component	% Distortion "Y" Component
1	High	Dalton	-0.080	-0.005
2			-0.084	-0.007
3			-0.085	-0.007
4		Tray	-0.090	-0.002
5			-0.091	-0.008
6			-0.086	-0.009
7			-0.089	+0.001
8			-0.091	-0.015
Average			-0.087	-0.007
9	Low	Dalton	-0.111	-0.018
10			-0.103	-0.019
11		Tray	-0.110	-0.018
12			-0.107	-0.013
13			-0.113	-0.019
Average			-0.109	-0.017

* The values tabulated are the results of a trial test program and are not considered statistically valid.

	Acetate Base	Estar Base
Humidity coefficient (Linear expansion, % per 1% R.H.)	0.0055 to 0.0100	0.0015 to 0.0035
Thermal coefficient (Linear expansion, % per degree F)	0.0025 to 0.0045	0.0015

It is apparent that changes of 10°F, 10% R.H. or combinations thereof can impose a significant effect, even when using the best available Estar materials. These figures point to the need for closely controlled ambient conditions.

(2) The Moiré technique is considered a workable method; however, additional effort should be given to advanced methods of interpreting patterns and presenting results. Funds for this project did not permit the construction of extensive computer programs to examine distortions along the diagonals of the halftone grids. Further information could be gained from calculating the standard deviation of the localized distortions in the X, Y, and diagonal directions. Currently, there is also under development in the photogrammetric industry a vector presentation method which uses a conventional digital computer controlled plotter to draw vectors throughout the distortion field whose directions correspond to the resultant direction of localized distortions and whose lengths are proportional to the distortion magnitudes.

(3) Improvements in the sensitivity of the Moiré technique are likely to become available soon with the advent of 1,000 lines per inch halftone grids. Fabrication in grids 9.5 inches wide may be difficult, however.

CONCLUSIONS

11. Printer evaluation test procedures discussed in this report provide a means of systematically comparing the performance of two or more contact printers, in those parameters which determine the ultimate quality of photographic reproductions. Within the limitations of each test, and given the specific requirements of a particular reproduction system, the performance study herein discussed should provide adequate knowledge of the capabilities of the printers in question.

12. For the degree of accuracy and precision needed in studies of this kind, better control of temperature and humidity is required. Lack of such controls prevents verification of test results except in relative terms.

13. Further investigation under proper study conditions holds the promise of better guides for printer design through more accurate measurement of the effects of the different printer components on resultant print quality.

14. Use of digital computer programs can result in faster, better, and more practical presentation of the distortion information available from Moiré pattern techniques.

15. Pending accomplishment of further study under improved conditions, a state-of-the-art survey of contact printers would be a worthwhile follow-on effort to this project.

RECOMMENDATIONS

16. Secure adequate facilities for experimental study conditions. Control of temperature and humidity for the study area should be a basic requirement.

17. Under controlled conditions, extend current studies on Moiré patterns to achieve these objectives:

a. Better guides for printer design.

b. Improved accuracy and precision for locating and measuring distortion.

c. More practical methods of presenting distortion information through the use of digital computer programs.

18. Conduct a state-of-the-art survey of contact printers using the test procedures of this report, after the above extension in studies is complete.

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APPENDIX 1

PRINTER TEST PROCEDURES

Test	Title
I	Basic Procedures.
II	Printing Uniformity -- Step-and-Repeat Printers (Streaking or Banding NOT Obvious).
III	Printing Uniformity -- Step-and-Repeat Printers (Identification of Obvious Streaking or Banding).
IV	Printing Uniformity -- Continuous Drum-Type Printers.
V	Printing Intensity Stability.
VI	Printing Intensity Reproducibility.
VII	Comparative Contrast Transfer.
VIII	Visual Resolution.
IX	Machine-Read Resolution.
X	Sharp-Edge Reproduction.
XA	"Maximum Gradient" of Sharp-Edge Trace.
XB	"Average Gradient" of Sharp-Edge Trace.
XC	"Edge-Width" of Sharp-Edge Trace.
XD	"Acutance" from Sharp-Edge Trace.

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Test I: Basic Procedures

Test Object: Film-copies of resolution, sharp-edge, sinusoidal, or halftone targets in each film width for which the printer can be used.

Test Procedure:

1. Adjust printer to optimum operating conditions, which will include:

a. Free-running and properly-aligned film rollers.

b. Properly-adjusted film supply and take-up spool drives and/or tension for continuous printers or platen pressure for step-and-repeat printers.

c. Careful elimination of dirt and lint from all printer surfaces and surrounding facilities.

d. Correct printing lamp intensity, light attenuation, and operating speed.

e. Correct positioning of all film supply and take-up spools; in general, this means centered with respect to the plane of exposure. For printers having multi-position capability, such as the inboard, center, and outboard positions for 70mm film on a 9 1/2-inch Niagara-type printer, each position should be individually tested with the appropriate width film.

2. Select the appropriate film for the test to be performed. Main considerations are:

a. The finest-grain film which can be adequately exposed on the printer is required for the study of imagery: resolution, sharp edge reproduction, contrast transfer, etc.

b. For distortion, uniformity, and reproducibility studies, the same film normally used for routine production systems will generally be a good choice. If the maximum dimensional stability is required, film on thick base (0.005 or 0.007 inch) Estar support should be used.

c. Film of the same width(s) as normally used for production printing should be used for all tests.

d. For each type of test to be performed, obtain an adequate supply of film of the same manufacturing batch number. If distortion tests are to be performed, it is especially important that all rolls of film have identical pre-exposure storage as well as conditioning before, during, and after exposure and processing.

3. Test objects are most commonly supplied on relatively short lengths of film -- often less than two feet. Preparation and handling of test objects involves the following principal points:

a. The test object must, in general, be on film the same width as that used for duplication. If dual-position printing is practiced, it may be appropriate to print a 70mm test object onto each of the three possible bands of a 9 1/2-inch wide duplicating film.

b. For use on continuous-type printers, leader and trailer must be attached to the test target; approximately fifteen to twenty feet of each should be used, of the same width and thickness as the test target. Great care must be exercised to have perfect alignment of the three sections of film, using butt-joints and thin splicing tape. Where practical, test objects should be on a continuous long length of film to eliminate the problem of splices. Storage of such long lengths should be on large diameter spools.

c. Prolonged storage of the test objects in rolls of small diameter should be avoided, particularly the halftone targets or others used for distortion studies. In the latter case, if utmost precision and accuracy is desired, flat storage is to be preferred.

d. Insofar as possible, all test targets should be maintained at approximately 70-75°F and 50% R.H., and protected from sunlight or prolonged ultraviolet exposure. If in roll form, they should be kept in sealed cans and protected from abnormal conditions of temperature and relative humidity.

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4. The room in which printing and test evaluations are performed should be air conditioned, and be as clean and free of lint as possible. If distortion studies are to be undertaken, very close control of temperature and relative humidity is essential; changes of 1°F or 1% R.H. will cause dimensional changes which can be detected.

5. When a test-object roll and a roll of duplicating film have been placed on a printer ready for printing to begin, observe the relative position of the two strands of film. In general, the edges should be perfectly aligned, as can be detected both by viewing under the usual red room safelights and by feeling the edges with a gloved hand. Observe the tracking of both strands as the films are advanced, particularly if splices are encountered. If the position of one strand changes with respect to the other, it may be necessary to re-make some or all of the splices to assure perfect alignment. If a random sort of poor tracking is observed, tension on one or both strands may be incorrect. Persistent erratic tracking will usually be due to misaligned film rollers.

6. Among the various items used for test evaluations, particular attention should be given the following:

a. Optics for visual determination of resolution should be of 200X magnification or greater, with adequate correction for both spherical and chromatic aberrations.

b. Illumination for microscopic examination may be a small incandescent lamp if a standard base-mounted microscope is used, or a backlighted opalized glass surface if a "hand" model microscope is used. Evaluations using different light sources should not be intermixed or directly compared.

c. For over-all illumination of large film areas, fluorescent light behind an opalized glass is to be preferred. Uniformity should be as good as possible, and, particularly for distortion measurements, heating of the viewing surface should be kept to a minimum.

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7. Keep all printed film samples for a given type test together at all times, so that any processing, drying, temperature, or humidity effects may equally involve each sample.

8. Whenever the human element may have a bearing on test conclusions, it is important to have the same person perform all of a given operation or evaluation. If a given set of evaluations of one type can be completed in one day, rather than prolonged over two or more days, better precision can be expected.

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Test II: Printing Uniformity - Step-and-Repeat Printers
(Streaking or Banding Not Obvious)

Test Object: None

Test Procedure:

1. Select one of the more commonly-used duplicating films, in the maximum width accommodated by the printer.

2. Insert into the printing beam the attenuating wedge or a neutral-density filter so that a processed-film density in the range of 0.8 to 1.2 can be achieved.

3. Make five identical exposures, and process the film in a continuous processing machine.

4. Divide each print into 16 equal segments (4 longitudinal, and 4 lateral divisions), excluding the area about one-half inch from the edges of the film. This is most readily accomplished by making a transparent over-lay the size of the exposure area, with five lines drawn in each direction to produce the desired segmenting. Make a small ink dot on the test exposure at each line-intersection of the over-lay.

5. Using a densitometer with a 2 to 4mm aperture, read the density near each intersection as located above. Avoid any obvious abnormalities such as digs, dirt spots, etc. Figure II-1 illustrates a suggested location-identification scheme, and Figure II-2 is a convenient form in which to record data and calculations.

6. For each of the ten rows of points on each sample, calculate the average density ($\bar{X}$) and range (R) from the 25 readings taken in 5, above.

7. If any range value exceeds 0.1, inspect the individual readings to determine if one is grossly unlike the others.

a. If so, make sure the reading was not in error.

b. Check the corresponding-location readings from the other samples; if all are similar (within 0.1 of each other), retain the reading in question.

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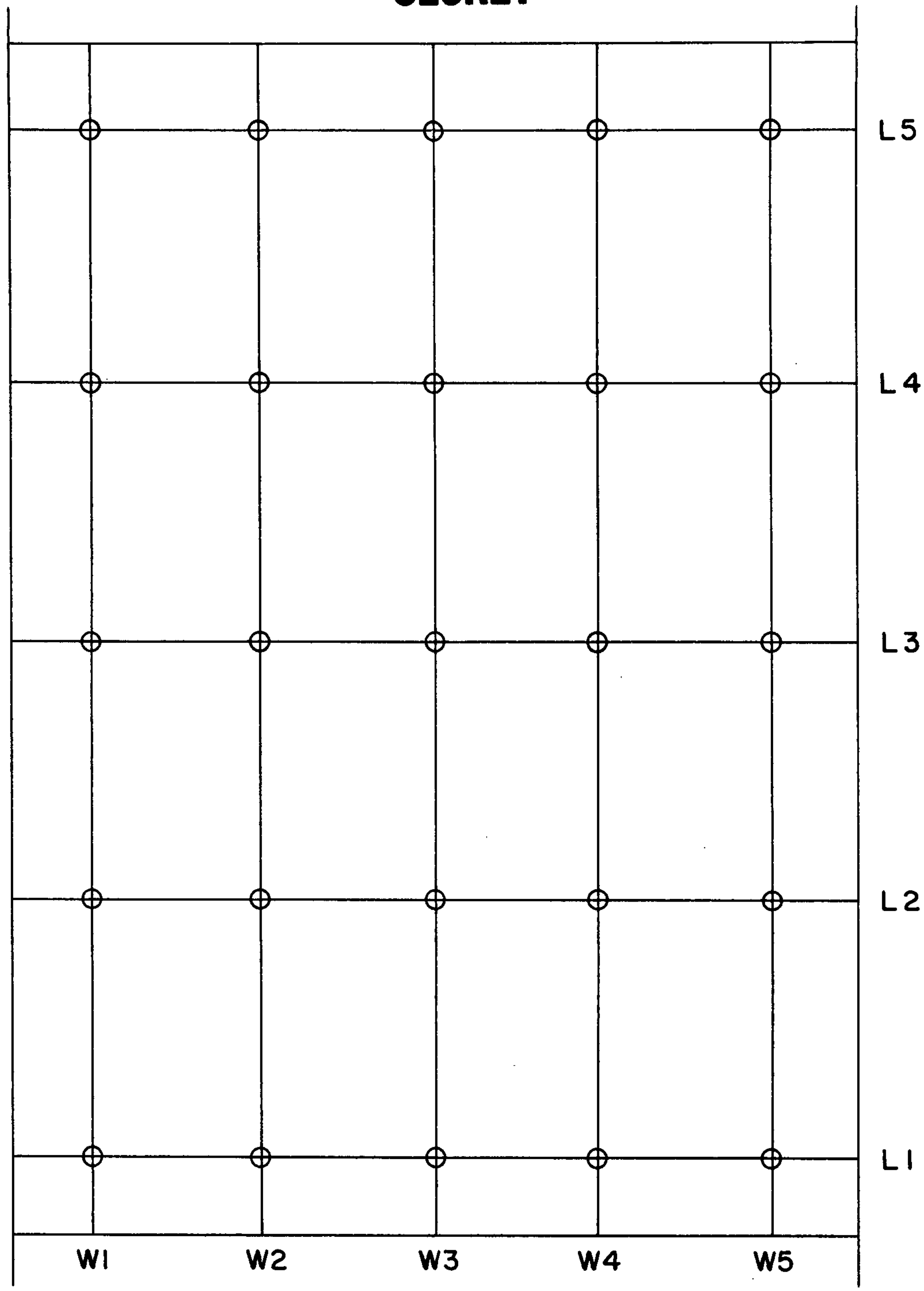

Figure II-1. Schematic for Uniformity Test Points

Samples:

READING LOCATION				A	B	C	D	E	Avg. ($\bar{X}$, $\bar{R}$)
	LONGITUDINAL	L1	$\bar{X}$						
			R						
		L2	$\bar{X}$						
			R						
		L3	$\bar{X}$						
			R						
		L4	$\bar{X}$						
			R						
		L5	$\bar{X}$						
			R						
	LATERAL	W1	$\bar{X}$						
			R						
		W2	$\bar{X}$						
			R						
		W3	$\bar{X}$						
			R						
		W4	$\bar{X}$						
			R						
		W5	$\bar{X}$						
			R						

Figure II-2. Data Sheet for Uniformity Readings

c. If it appears the reading is just a single abnormality, it may be ignored.

8. Using the individual averages ($\bar{X}$) and ranges (R) from step 6, with possible corrections from step 7, calculate the grand average ($\bar{X}$) and average range ($\bar{R}$) for each of the ten row-locations.

9. On a graph such as illustrated in Figure II-3, plot the $\bar{\bar{X}}$ values for each row-location. Connect the five W-points,* and the five L-points.**

10. If either line tends to slant, or has a hump or sag in the middle, there is non-uniformity present.

11. If any of the $\bar{R}$ values exceed 0.1, this is further indication of non-uniformity.

COMMENTS

Should non-uniformity be present to a degree which can affect the quality of the duplicate prints, it would be well to carefully re-inspect the printer for dirty or defective attenuators, improperly positioned or over-aged lamp, or questionable electrical components. Processing may also be the cause; check agitation, solution condition, idler rollers, and drive mechanism.

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* W = width, or lateral points across the web.

** L = length, or longitudinal points along the web.

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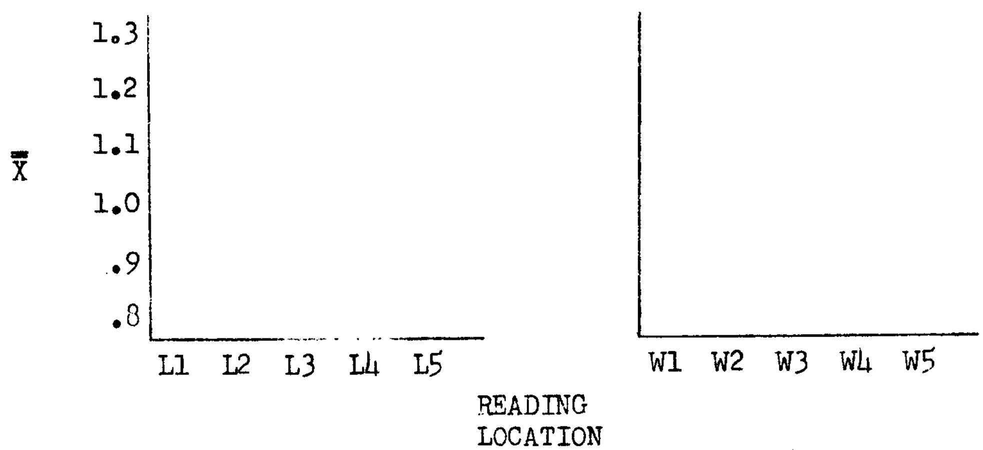

Figure II-3. Plotting Scheme for Uniformity Readings

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GROUP 1
EXCLUDED FROM AUTOMATIC DOWNGRADING AND DECLASSIFICATION

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Test III: Printing Uniformity - Step-and-Repeat Printers
(Identification of Obvious Streaking or Banding)

Test Object: None

Test Procedure:

A. For longitudinal streaking.

1. Procure a length of duplicating film sufficient for six exposures-approximately 20 feet.

2. With a hand punch or sharp stylus, make a very small hole or scribe-mark at intervals along one edge, to positively identify one of the edges of the film as manufactured. Refer to Figure III-1 for further identification nomencalture. In this and all following figures, the emulsion side of the film is toward the operator.

3. Cut off one-third of the length from step 1, switch the short piece end-for-end, and splice onto where the cut was made.

4. Place a small opaque marker at one edge of the printer aperture, to produce a distinguishable identification for "same printing position" for each exposure.

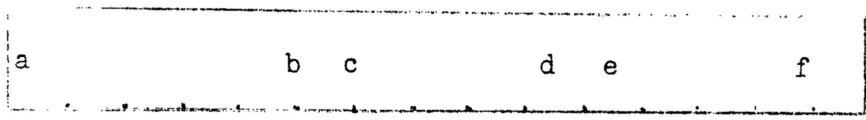
5. Make six identical exposures: two on the short section, four on the long section. A processed density of 1.0 ± 0.20 is preferred. Refer to Figure III-2.

6. Before processing, cut off half of the long section (should contain two exposures), switch end-for-end, and splice onto where the cut was made.

7. Process the entire length together, and immediately identify each section as indicated in Figure III-3. The splices may now be removed for the evaluation to follow.

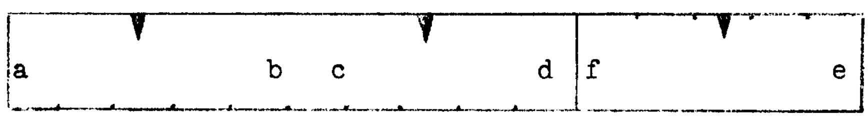
Scheme for Streaking and Banding* Tests

Fig. III-1: Identification of Film Edge Prior to Printing



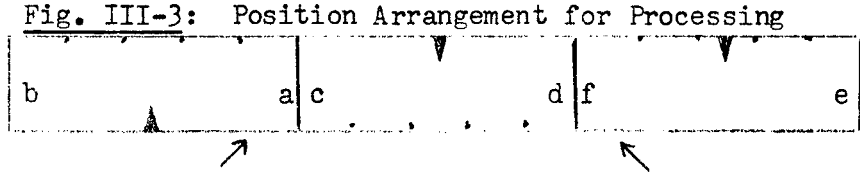
(Edge Markings)

Fig. III-2: Position Arrangement for Printing



(Printer Markings)

Fig. III-3: Position Arrangement for Processing



(Sequence Lettering)

Original lead-end of test strip

Original tail-end of test strip

* For lateral banding tests on films wider than five inches, see Figs. III-8 through III-13.

8. Referring again to Figure III-3, re-align the sample ends as indicated below and carefully note the location, size, and density differences of any apparent streaks. As the film lies over a large illuminated surface, it may be of value to view the adjoining ends at a low angle parallel to the film length.

a. Ends "a" and "c" together: if streaks coincide, they are due to processing.

b. Ends "a" and "f" together: if streaks coincide, they are due to processing or the film itself.

c. Ends "d" and "f" together: if streaks coincide, they are due to processing or printing.

Note that it is necessary to evaluate step 8a above, in order to pinpoint the conclusions from steps 8b and 8c.

B. <u>For lateral banding of films less than five inches wide</u>.

1. Follow steps 1 through 7 above. Then the three samples are compared lying side-by-side rather than end-to-end. View the samples from a low angle, and perpendicular to the length-direction.

2. If the streaks do not appear to match in spacing, density, and size, shift one film sample to the left and then to the right in search of a possible repetitive streak cycle.

3. If a match is still not found, replace one of the samples with the corresponding duplicate sample. Search for matching streaks as before.

4. If matching streaks are found, identification of the cause is as follows:

a. With ends "c" and "e" together, matching streaks indicate probable manufacturing defect. Refer to Figure III-4.

b. With ends "b" and "c" together, agitation or irregular film advance in processing is the probable cause. Refer to Figure III-5.

Lateral Banding Tests for Narrow Films

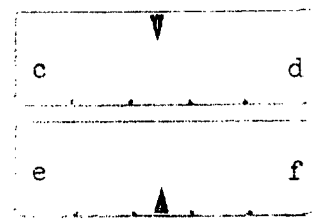


Fig. III-4: Matched bands indicates cause by manufacturing condition.

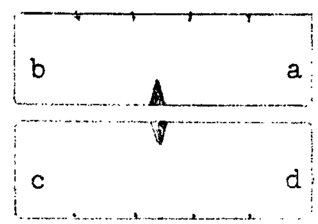


Fig. III-5: Processing responsible.

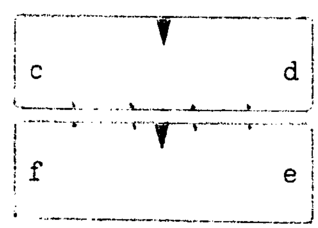


Fig. III-6: Processing <u>or</u> Printing.

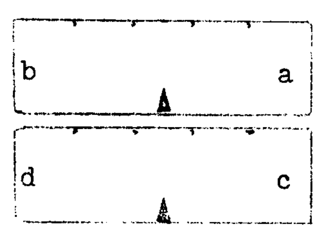


Fig. III-7: Printing <u>or</u> Manufacturing.

c. With ends "c" and "f" together, either processing or printing is responsible. Refer to Figure III-6.

d. With ends "b" and "d" together, either printing or film manufacturing is the probable cause. Refer to Figure III-7.

Note that it is necessary to evaluate steps 4a and 4b before final conclusions can be drawn from steps 4c and 4d.

C. For lateral banding (wide films).

1. The foregoing procedure of Section B is sometimes inconclusive, particularly if the bands are widely separated. This procedure is better, but practical only for wider films: five inches or more.

2. Procure a length of duplicating film; several feet may be used but the minimum is three times the width measurement.

3. Identify one edge of the sample at short intervals, as in step A2. See Figure III-8 (emulsion up for all figures).

4. Cut off a piece at one end as long as the film is wide. Turn 90° and splice onto the large section.

5. Place small opaque markers at short intervals along one edge of the printing aperture, as in step A4.

6. Make identical exposures throughout the prepared film strip, so that a processed density of 1.0 ± 0.20 will be obtained. Refer to Figure III-9.

7. Before processing, remove a piece from the longer section as long as the film is wide. Turn 90° and splice onto the remaining length. Refer to Figure 10 for the completed sample identification.

8. Process the spliced sample, and then immediately label each section as in Figure III-10.

9. It may be necessary to repeat the above steps 2 through 8 several times to draw positive conclusions.

Lateral Banding Tests for Films Wider than Five Inches

Fig. III-8: Edge Identification

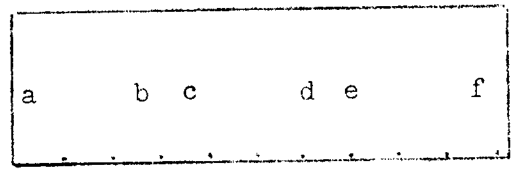


Fig. III-9: Printing Arrangement

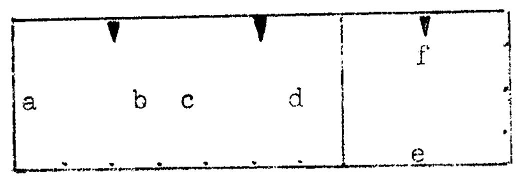
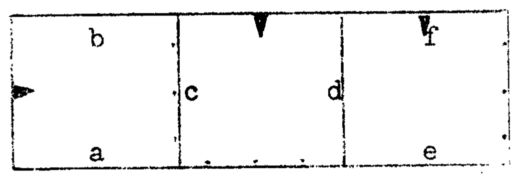


Fig. III-10: Processing Arrangement



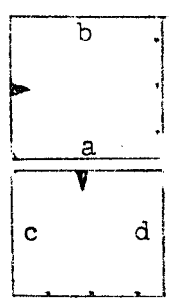


Fig. III-11

Processing

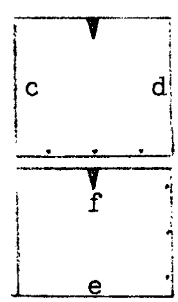


Fig. III-12

Processing or Printing

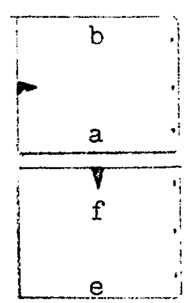


Fig. III-13

Processing or Manufacturing

10. The individual sections within a spliced sample are now compared as before, with the orientation as illustrated:

a. With end "a" by side "c-d," if the streaks or bands match, processing is probably responsible. Refer to Figure III-11.

b. With end "f" by side "c-d," if the streaks or bands match, either processing or printing is probably responsible. Refer to Figure III-12.

c. With end "a" by end "f," if the streaks or bands match, either processing or film manufacturing is probably responsible. Refer to III-13.

Note that evaluation 10a must be made before final conclusions can be drawn from steps 10b and 10c. Note also that longitudinal streaks often can be identified by this procedure, but the procedure of Section A is preferred for this purpose.

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Test IV: Printing Uniformity - Continuous Drum-Type Printers

Test Object: None

Test Procedures:

1. The same procedures, with minor modifications, can be used for this type printer as for Step-and-Repeat Printers. Refer to the following tests:

   a. For longitudinal streaks - Test II.

   b. For lateral streaks and "banding" - Test III B, and C.

2. The only modification to the above tests concerns the exposed length. Because a continuous fogging exposure does not produce finite "frames," it is only necessary to arbitrarily select a convenient-length portion of an exposed section. This "artificial frame" may be as long as the average negative frame normally used on the printer, or may be as short as required by Test III C (as short as the film width).

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Test V: Printing Intensity Stability

Test Object: Calibrated Silver Step-Tablet

Test Procedure:

1. The following basic assumptions apply to this test, and to Test VI, "Printer Intensity Reproducibility."

a. A means has been provided for "zeroing" the printer, such as a self-contained photo-voltaic meter, lamp power control, exposing time and/or aperture, etc.

b. Streaking, banding, or other known occurrences of non-uniformity are minimal or readily detectable if present. Refer to Tests II and III if uncertain.

c. Electrical power supply to the laboratory is adequate for expected loads, and drops or surges in voltage beyond the capacity of control units are unlikely.

d. An accurate densitometer is available, properly maintained and calibrated.

e. The same processing machine and formulations will be available throughout the entire test period.

f. An adequate supply of film, all of the same batch number, can be provided for the entire test and can be kept under refrigeration.

g. Zero-degree storage is available for all exposed film to be held over four hours before processing.

h. Sensitometric process-control strips are available.

2. Turn on the printer, allow to warm up the recommended time, and adjust to "zero" or other standard condition.

3. Using the selected duplicating film supply, determine the exposure which will yield a full-scale reproduction of a calibrated silver step tablet.

4. Make three identical exposures, and immediately refrigerate the exposed samples at a temperature below 40°F.

5. Provide for continuous operation of the printer throughout a normal working day. A minimum of eight hours is suggested. The film advance mechanism need not be constantly running as long as the lamp remains at its normal printing intensity at all times.

6. At 30-minute intervals, repeat step 4.

7. At the end of the test period, process all exposed samples together, adding a sensitometric process-control strip at the beginning and end of the set.

8. Select three steps on the processed step-wedges having densities within the approximate range of 0.50 to 1.50. Use these same steps for all subsequent evaluations.

9. Read the two process-control strips. If any two corresponding steps fail to agree within ±0.05 density, there may be enough process variability to cause uncertainty in the printer tests.

10. Read the printer-exposed step tablets, checking first for streaks, spots, or other anomalies. Determine the averages ($\bar{X}$) and ranges (R) for the corresponding steps of each set of three exposures.

11. Determine the grand average ($\bar{\bar{X}}$) and average range ($\bar{R}$) for the corresponding steps of all groups of samples.

12. If any range exceeds 0.05, excessive variability is present. Check all readings for possible errors, and re-inspect the samples for possible visible explanation of the condition.

13. On a graph of average density versus hours, plot the calculated $\bar{X}$ values. Draw a straight line at the three $\bar{\bar{X}}$ values to indicate expected densities.

14. If any single point is over 0.03 from its $\bar{\bar{X}}$ level, or there is an apparent tendency for the lines of points to rise or fall with time, there is an indication of variability in the printer.

Test VI: Printing Intensity Reproducibility

Test Object: Calibrated Silver Step-Tablet

Test Procedure:

1. Refer to Test V, "Printing Intensity Stability," for the basic test requirements.

2. Using the self-contained photo-voltaic meter, or other direct (non-photographic) means of establishing a "zero" or other indicated "standard" exposure setting, adjust the printer to the normal operating level.

3. Determine the added light attenuation or other printing adjustment necessary to produce a full-scale reproduction of the silver step-tablet on the selected duplicating stock. Use this exposing condition for all subsequent testing.

4. Once per day, make three identical exposures. Either process immediately, or place the exposed film in zero-degree storage until several days' accumulation can be conveniently processed. In either case, include two process-control strips with each group of printer samples.

5. Select three steps which fall within the approximate density range of 0.50 to 1.50. Use these same steps for all subsequent evaluations.

6. Obtain densitometric readings of all samples. Calculate the average ($\bar{X}$) and range (R) for the corresponding steps in each set of two process or three printer samples.

7. Using a previously determined "process standard" for each of the three selected steps, determine whether the day's process control strips were above or below standard. Apply any differences to the averages of the printer samples processed that day, to obtain "corrected" printer averages ($\bar{X}'$).

8. On a graph of average density versus date, plot $\bar{X}$ for each step each day of the test. Use the averages of the first five days as the printer "aim point" or standard. Any deviation of a point from this aim of over 0.03 calls for investigation and/or remedial action.

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Test VII: Comparative Contrast Transfer

Test Object: Sinusoidal Test Object

Test Procedure:

1. Each target on the test object has a lateral and a longitudinal component. Select two or more targets near each edge and two or more down the center of wide-format test objects, or two or more targets on each side of a narrow-format test object.

2. Using very-fine-grain duplicating film, print an exposure series at 0.1 ND attenuation increments.

3. Visually inspect the series to find the best exposure (highest resolution, or most clear reproduction of the finest "bars"). Select this print and the one on either side of it for further study.

4. Using a microdensitometer, trace both the lateral and longitudinal component of each target.

5. Similarly, trace the same targets on the original test object.

6. From the microdensitometer traces, determine the average density difference (ΔD) for each line frequency of each target component.

7. For each line frequency taken separately, calculate the average ΔD for all the target components of the original and the prints at each printing density.

8. From the calculations of step 7 above, retain only the tabulated ΔDs of the original test object and of the print having the highest values.

9. At selected line frequencies (10 to 20 1/mm apart), determine the quantity $\frac{\Delta D \text{ Print}}{\Delta D \text{ Original}}$.. This gives the contrast transfer at each selected frequency. Selected frequencies should span the resolution capability of the duplicating material used for the test.

10. Divide each of the values calculated in step 9 above by the largest value, which will be found at the minimum (coarsest) line frequency. These "normalized" values then represent the relative contrast transfer at each frequency.

11. Plot the values from step 10 versus line frequency, as shown in Figure 1 of the report. From this graph, determine these parameters:

a. Maximum resolution. (Arbitrarily taken at 5% response level.)

b. Contrast transfer of "fine" lines - arbitrarily taken at 100 lines/mm.

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Test VIII: Visual Resolution

Test Object: United States Air Force Resolution Target (1951) or United States Air Force Resolution Target (1962-Visual), in High Contrast and Low Contrast Forms.

Test Procedure:

1. If an approximate "best exposure" is known, use this as the middle condition of an exposure series; a printing density range of 0.4 ND above and below this figure should be used, in increments of 0.1 ND. Repeat for both contrasts.

2. If an optimum exposure is not known, an exposure series should be made spanning the normal range of the printer, in increments of 0.1 ND.

3. After processing, each exposure of the test-object must be microscopically examined. Grossly under- or over-exposed samples, having obviously degraded resolution should be discarded.

4. For each usable exposure, each target in the test object array should be read. To minimize the problem of consistent judgment as to what line of frequency has been resolved, the following rules are suggested:

a. The three bars in each direction should be clear enough so there is no question as to how many bars were actually present in the original target.

b. Each bar should appear as a bar of full length.

c. If two adjacent bars are joined by a random single silver grain or grain cluster, but other bars of the same line frequency are clearly separated, the group can be considered to be resolved.

d. Have one trained observer make all readings for the test.

5. Using the above rules, determine the maximum line frequency resolved for each target of the array, at each exposure. Note the calibration readings for the original test object, and if any individual targets had poor resolution these should be ignored in the reproductions.

6. Calculate the average of all usable targets for each exposure level.

7. Plot the averages for each exposure level on a graph having "lines per millimeter resolved" on the ordinate and "exposure level" (N.D. in printing beam) on the abscissa. Draw a smooth curve through the individual points. If the curve does not reach a true maximum, with lower readings at the extremes of the curve, a new exposure series must be printed until such a curve shape is obtained.

Evaluation:

From the graph in step 7 above, record the highest point of the curve as the best resolution of the particular printer-film-process combination being tested, for each of the two contrasts.

Do not attempt to compare printers which have been evaluated with two different resolution test objects. "Corrections" for indicated differences in calibrations may not be adequate for dependable conclusions.

Test Reliability:

1. If the average values plotted in step 7 above fall very close to the smooth curve, good precision is indicated for all phases of the test. If the average values are more randomly arranged, one or more of these problems may have been encountered:

a. Inconsistent printer performance.

b. Foreign matter between the duplicating film and individual test targets at the moment of exposure.

c. Inconsistent operator judgment in reading individual targets.

d. Mathematical errors.

2. An experienced operator may vary plus or minus one line-frequency grouping from his initial judgment in any one brief time period, although the averages of ten or more targets will generally agree within a fraction of this -- probably within 10-15 lines/mm in the neighborhood of 400 lines/mm.

3. Unless an operator repeatedly reviews the basic "rules" for reading resolutions, his averages may tend to drift higher or lower, over a period of weeks or months, by the equivalent of one line-frequency grouping.

4. Two different operators may show an additional variability due to different interpretations of the "borderline cases," which may be rather frequent.

5. With careful attention to all likely sources of variability, a long-range over-all precision of ±10% can be expected.

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Test IX: Machine-Read Resolution

Test Object: United States Air Force Resolution Target (1962) Machine-Readable, in High Contrast and Low Contrast Versions.

Test Procedure:

1. The test object consists of individual targets arranged laterally and longitudinally at various locations along its width and length. At least six targets in each position should be selected, at representative locations. Repeat for both contrasts.

2. Using very-fine-grained duplicating film, print an exposure series at 0.1 ND increments.

3. Visually inspect the series to find the best exposure (highest resolution, or most clear reproduction of the finest bars). Select this print and several on either side of it for further study.

4. Using a microdensitometer, trace both the lateral and longitudinal component of each target.

5. Inspect the trace of each component; select the finest line frequency where it is just possible to distinguish between "bars" and "spaces."

6. Average all of the individual resolution values as determined in step 5, for each of the prints selected in step 3.

7. Report the maximum value calculated in step 6 as the resolution of the printer-film-process combination in question, at each of the two contrasts.

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Test X: Sharp-Edge Reproduction

Test Object: Experimental Sharp-Edge Test Object

Test Procedure:

1. The above target has eight sharp edges in each of two directions, with a total of four basic densities (actually, "delta-densities," measured on both sides of an edge). Select any one transverse and any one longitudinal edge to be used for all evaluations; they should have comparable delta-densities.

2. Expose the target onto the appropriate duplicating film so that the processed low-density side of the selected edges has a density within the range 0.2 to 0.5. Repeat four more times so that five test target prints are made at essentially matching densities.

3. Position one of the selected edges in the microdensitometer so that one of three printed reference marks (part of the test object) is in the path to be traced. Be sure the sharp edge is precisely perpendicular to the trace path. The actual trace may be made from the heavy density into the light density, or vice versa, but the same orientation must be used for all samples within a test or among tests to be inter-compared. Similarly, position and trace at the other two reference marks.

4. Repeat the positioning and tracing at each of the three reference marks, for each edge of each target print. Since the reference marks may appear quite large and irregular under the magnifying viewer of the microdensitometer, a prominence or other selected portion of the reference mark should be used for increased precision of positioning.

5. Evaluate the microdensitometer traces of the sharp edges by one of the following four procedures:

   a. Test XA: "Maximum Gradient."
   b. Test XB: "Average Gradient."
   c. Test SC: "Edge Width."
   d. Test XD: "Acutance."

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Comments and Precautions:

1. As was discussed in the report section dealing with modulation transfer, single-parameter measurements of image quality cannot take into account all pertinent factors. Because the above procedures are single measurements, and each a bit different, they cannot be expected to correlate among themselves except under special circumstances. However, if two printers are being compared, all procedures should indicate the same ranking.

2. To avoid unwarranted conclusions, do not attempt to compare:

a. Any results except averages of at least ten individual readings.

b. Any microdensitometer test readings not based on identical calibrations.

c. Different test objects.

d. Different edges on the same test object.

e. Different processed densities of the same edge (should be within 0.1 of the average density).

f. Different portions of the same edge. Despite advanced technology, any given edge is not necessarily uniform enough to permit random selection of the locations to be read.

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Test XA: "Maximum Gradient" of Sharp-Edge Trace

Method: Graphical

Test Procedure:

1. The microdensitometer trace of each sharp edge will be a curve shaped very much like the conventional photographic H & D curve. Locate the portion of the curve which has the steepest slope.

2. Using a photographic gradient meter, determine the slope of this part of the curve, or,

3. Determine the vertical (Y) and horizontal (X) components of a right triangle whose hypotenuse is drawn tangent to the steepest part of the curve. Determine Y/X for each curve.

4. Calculate the average of the thirty individual slope values which constitute one test series (per Test X).

5. Report this single value as the result of the test.

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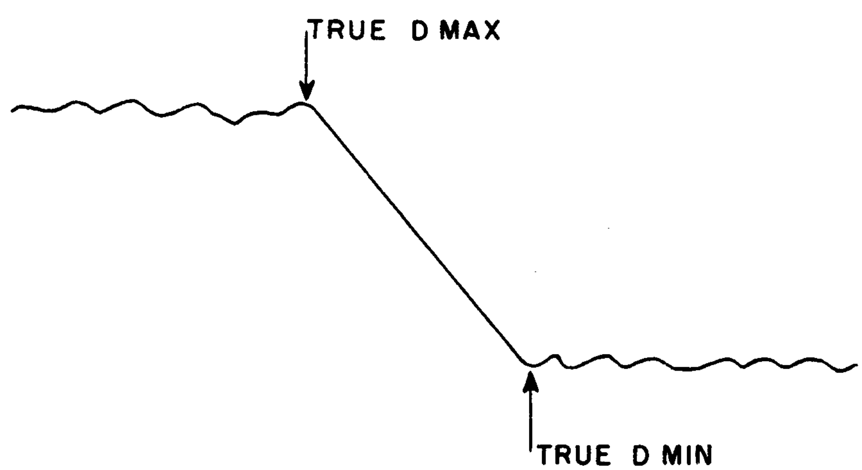
Test XB: "Average Gradient" of Sharp-Edge Trace

Method: Graphical

Test Procedure:

1. A typical edge-trace curve is shown below, with pertinent features identified:



2. Locate the true Dmin and true Dmax as shown; similar values noted farther away from the edge trace are generally experimental anomalies and should be ignored.

3. Draw a straight line between the two true extreme values, as shown. Measure the slope of this line (vertical change per unit horizontal change).

4. Repeat the above for each of the fifteen edge locations which constitute one test series, and obtain the average of the resulting thirty traces.

5. Report this average as the test value.

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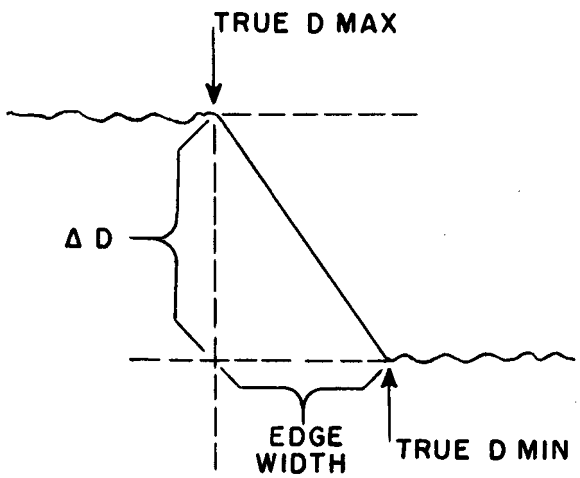
Test XC: "Edge-Width" of Sharp-Edge Trace

Method: Graphical

Test Procedure:

1. The true extreme densities of the edge trace curve are determined as in Test XB.



2. The "edge width" is defined as the horizontal distance between the two density extremes, for a given microdensitometer calibration.

3. If the "delta-densities" of all samples in one test series are not within about 0.1 of each other, correction for the differences is accomplished as follows:

a. Tabulate the delta-density ($\triangle$D) and the measured edge-width (W) for each sample.

b. Divide each $\triangle$D into the maximum $\triangle$D of the entire lot of samples, to obtain a correction factor (cf) for each edge.

c. Multiply each measured W by the cf to obtain a "corrected" edge-width W'.

d. A convenient table for organizing these calculations is as follows:

Edge Number	Measured $\triangle D$	Measured Width W	$\frac{\triangle D \text{ Maximum}}{\triangle D \text{ Measure}} = cf$	Corrected Width W'
1	-	-	-	-
2	-	-	-	-
3	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
15	-	-	-	-

e. Calculate the average "corrected edge width," W', to obtain a single value to report for the test result.

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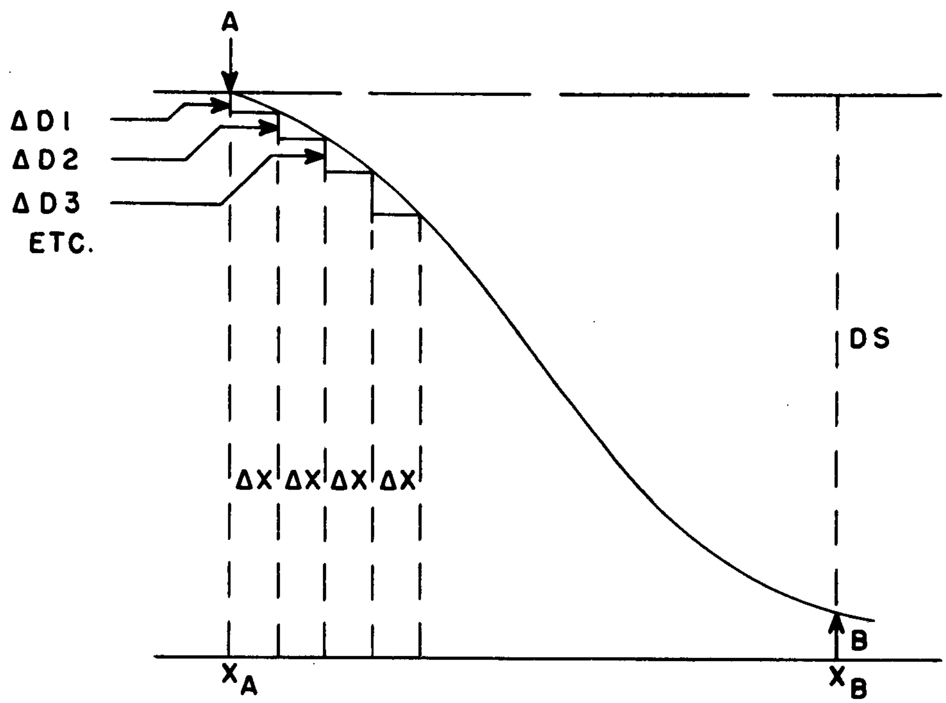
Test XD: "Acutance" from Sharp-Edge Trace

Method: Calculation

Test Procedure:

1. For the sake of clarity, the typical edge-trace curve illustrated in Tests XB and XC will be modified so that appropriate labels can be applied:



2. The end-points A and B are normally specified as being at the point where the curve gradient is 0.005, when the distance X is measured in microns.

3. Divide the curve into small segments of equal increments as measured in the distance-direction (ΔX).

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4. At each segment, determine the vertical component, $\triangle D$, and calculate the quantity $(\triangle D/\triangle X)^2$.

5. Sum all the quantities calculated in step 4, and divide by the number of quantities used to give the "mean square of the gradient."

6. Divide the gradient mean square by the total density scale, DS; this yields the parameter ACUTANCE.

7. Repeat steps 2 through 6 for each curve of the test series; add all the calculated acutance values together and calculate the average acutance. This latter value is the single result reported for the test.

APPENDIX 2

TEST OBJECTS USED IN THIS STUDY

Targets for Comparative Contrast Transfer.

Figure 1: Sinusoidal Test Object-Schematic Illustration.

Visual Resolution Test Objects.

Figure 2: United States Air Force Resolution Test Object (1951).

Figure 3: United States Air Force Resolution Test Object (1962).

Machine-Readable Resolution Test Objects.

Figure 4: United States Air Force Resolution Test Object (1962)-Machine Readable.

Figure 5: National Bureau of Standards Resolution Test Object (1952)-Machine Readable.

Sharp-Edge Test Objects.

Figure 6: Photographic Sharp Edge Test Object.

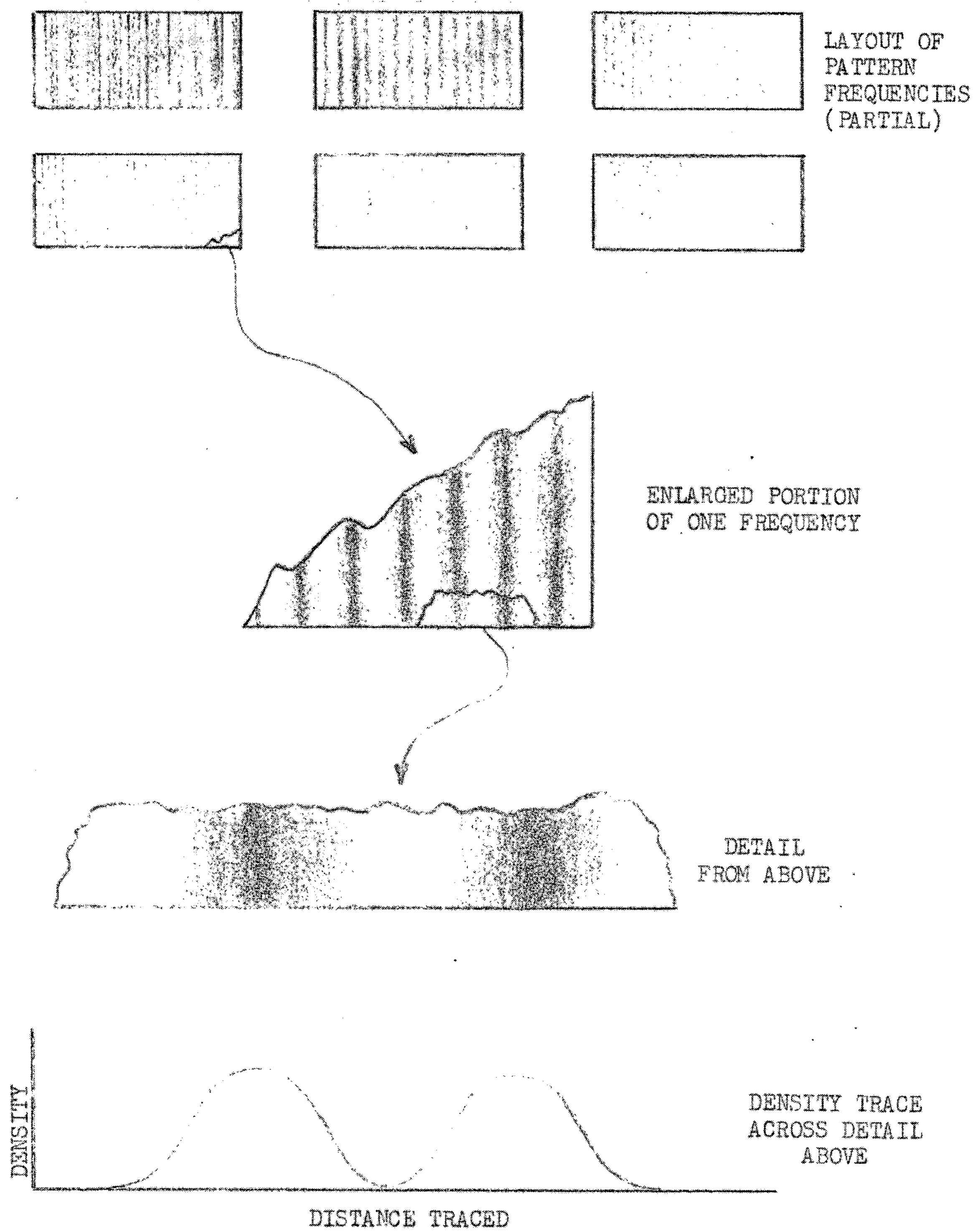

Figure 1. Sinusoidal Test Object - Schematic Illustration

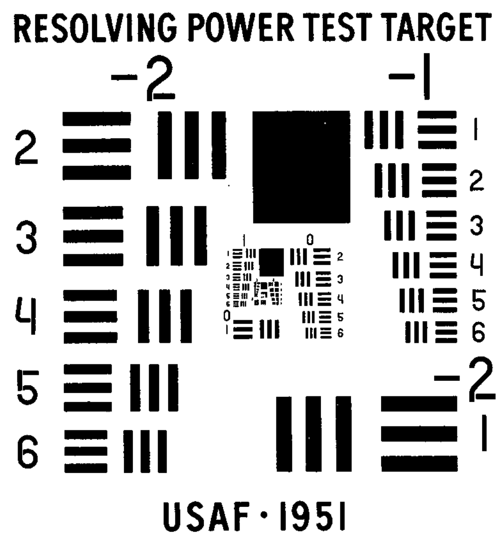

Figure 2. United States Air Force Resolution Test Object (1951)

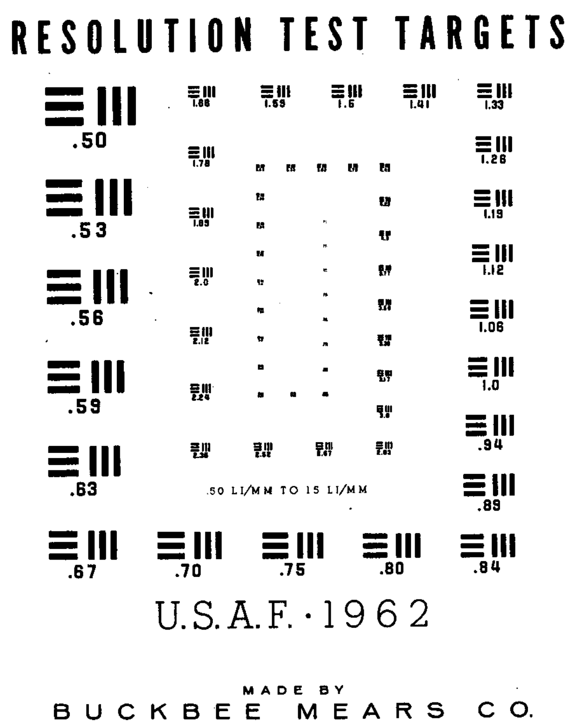

Figure 3. United States Air Force Resolution Test Object (1962)

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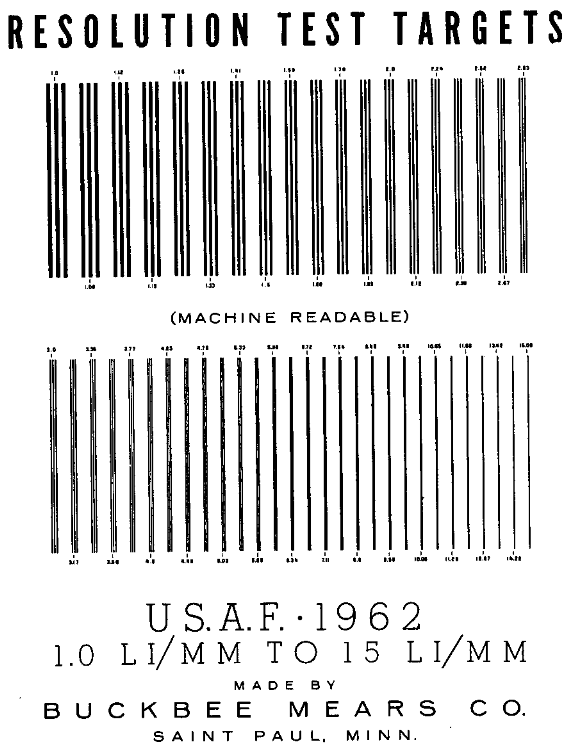

Figure 4. United States Air Force Resolution Test Object (1962) - Machine Readable

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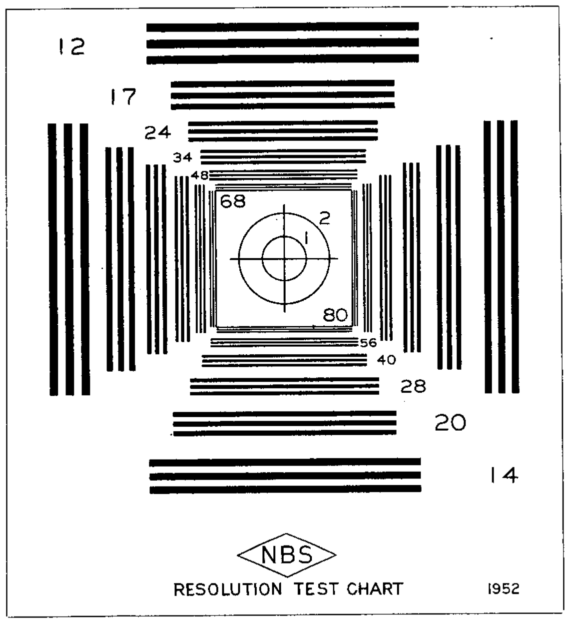

Figure 5. National Bureau of Standards Resolution Test Object (1952)
Machine Readable

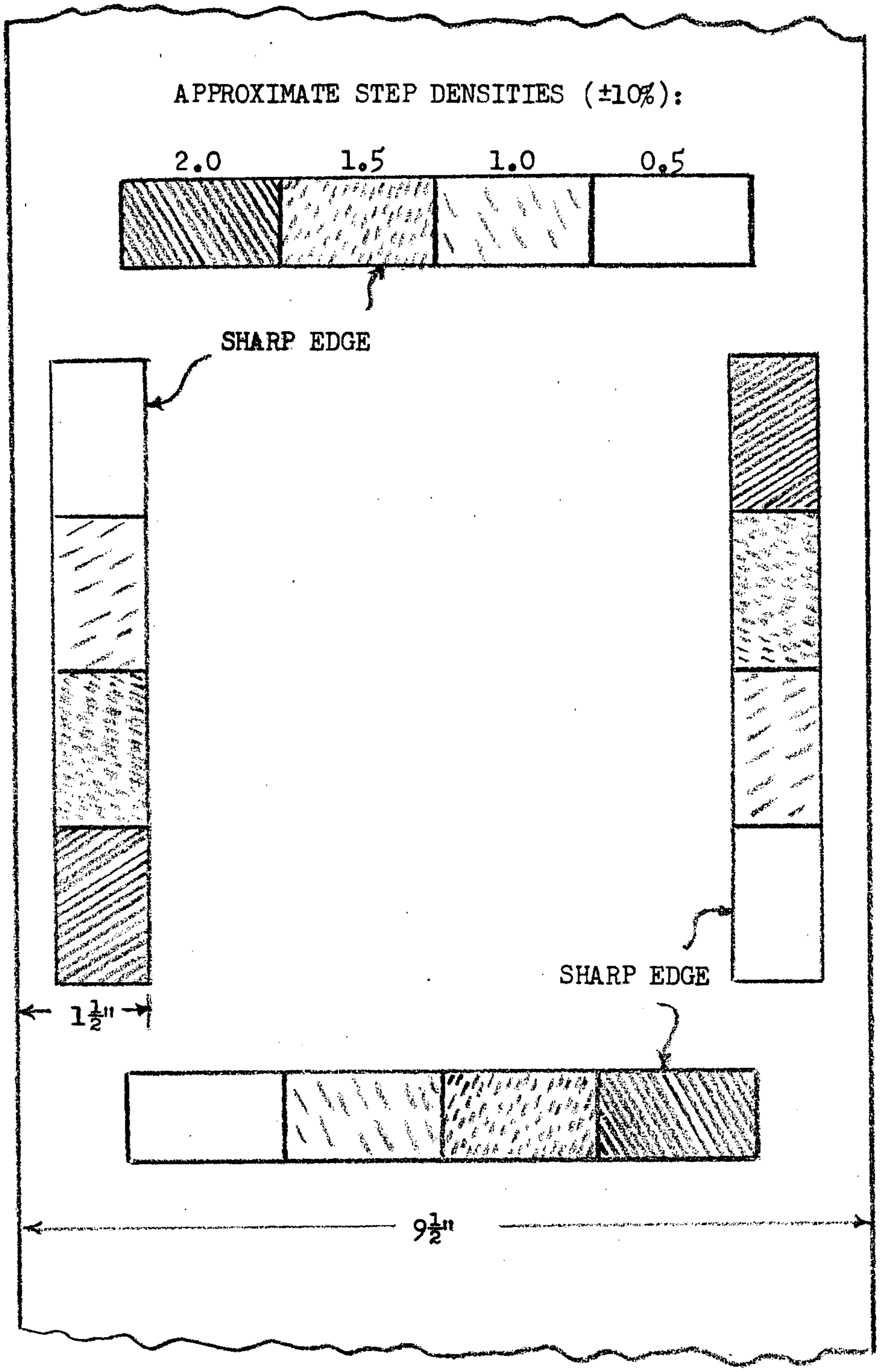

Figure 6. Photographic Sharp-Edge Test Object

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APPENDIX 3

SUGGESTED DUPLICATING FILMS FOR PRINTER EVALUATIONS

Group A   Medium- to fine-grained films for distortion, uniformity, and reproducibility tests:

Type 5427

Type 2427

Group B   Fine-grained films for resolution, sharp edge, and sine wave tests:

Type 8430

SO-242 (tungsten illumination)

Group C   Ultra-fine-grained films for imagery studies beyond the capabilities of Group B films. Because of their very slow photographic speed, continuous-type printers will generally need a change in the drive mechanism.

Type 649-GH

SO-107